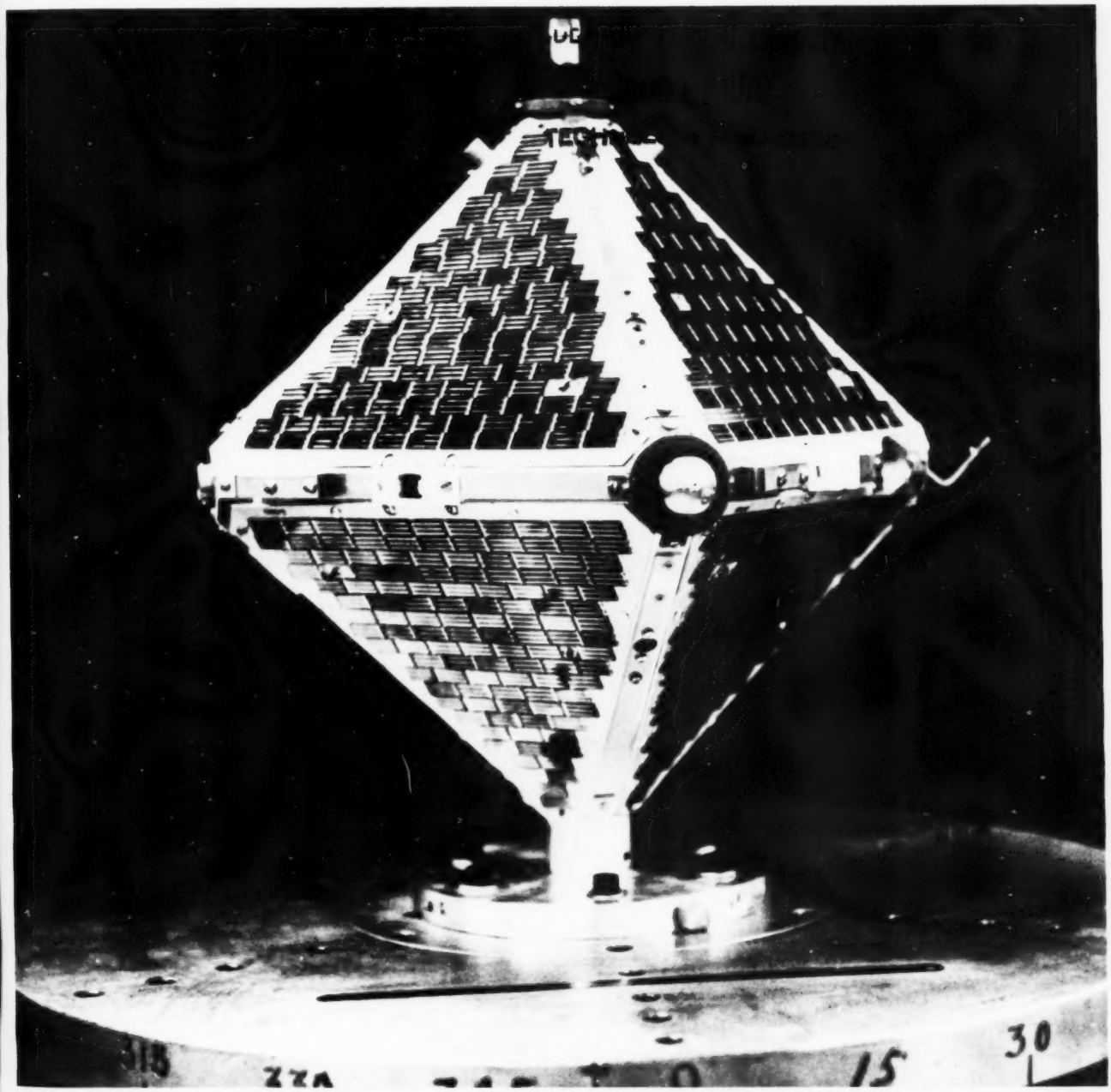
US 6
A32 AI

TS

OAR RESEARCH REVIEW

VOLUME IX NUMBER 3 MAY-JUNE 1970



OFFICE OF AEROSPACE RESEARCH ★ UNITED STATES AIR FORCE

OAR RESEARCH REVIEW

VOLUME IX NUMBER 3 MAY-JUNE 1970

OAR: The Research Agency of the United States Air Force

ON THE COVER:

SMALL SATELLITE, BIG RETURN: Almost a year ago, the OV5-6 satellite was sent into orbit as one in a cluster of satellites aboard a Titan IIIC booster. The small, 25-pound, eight-sided, low cost satellite was placed in a high elliptical orbit of 9,100 by 60,000 nautical miles. This orbit takes the satellite into and out of the earth's radiation belts, permitting measurements of solar particles directly from the sun and particles in the radiation belts. The OV5-6's performance has greatly exceeded expectations, providing a wealth of significant data on the earth's near-space radiation environment—data that is essential to the evolution of the Air Force's Space Forecasting System. This ambitious System will project solar variations in terms of terrestrial effects that alter the performance of radio and optical sensors. Dr. Kenneth Yates of AFCRL is the project scientist.

OAR RESEARCH REVIEW is published bimonthly by the Directorate of R&D Interactions (PGRO), HQ Office of Aerospace Research, USAF, 1400 Wilson Boulevard, Arlington, Va. 22209. The objective of this publication is to make a positive contribution to the exchange of information concerning Air Force conducted and sponsored research activities.

ETHEL GAMER *Editor*

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 – $3.00 per year domestic, 75 cents additional for foreign mailing, 45 cents per single copy and 30 cents per Annual Index. Back issues will not be furnished.

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED.

OARRP 80-1

COMMENTS TO THE EDITOR

To stimulate a dialogue between the readers and our scientists, we welcome your comments and suggestions. We are most interested in your views on the following:

The Editor

1. I consider the most significant article in this issue to be _____

because _____

2. I suggest the following applications of the research described in this issue _____

☐ You may publish the above suggestions with my name in a subsequent issue of the *OAR Research Review*.

☐ You may publish the suggestion anonymously.

☐ You may not publish the suggestion.

3. I would like more information on the following article _____

NAME _____

ORGANIZATION _____

STREET AND NUMBER _____

CITY, STATE AND ZIP CODE _____

TELEPHONE _____ SPECIALITY _____ _____

(Include Area Code
or AUTOVON Number)

OAR (PGRO)
1400 Wilson Blvd.
Arlington, Va. 22209

UNITED STATES AIR FORCE
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
DEPARTMENT OF THE AIR FORCE

HQ OAR (PGRO/REVIEW)
1400 Wilson Boulevard
Arlington, Virginia 22209

foreword

The new Directorate of R&D Interaction (PGR) of DCS/Programs combines the scientific and technical information focal point activities with the functions of the former publications and technical applications offices. Its objectives are the enhancement of interaction activity and communications efforts between producers and users of research, between scientists and engineers.

The Readers Interchange is being introduced with this issue of the OAR Research Review both to encourage reader participation and to suggest further basic research for the scientist and new product development for the engineer. Contributions by OAR and the readers will be under four general headings, each with its own special function: Research Advances, Invention Disclosures, Research Needs, and Speculative Ideas. Research Advances will be presented from material furnished in coupling reports on research advances from our internal research laboratories and research sponsors: AFCRL, ARL, Det. 8, (ORA) OAR, AFOSR, FJSRL, and EOAR. Invention Disclosures will be selected from current invention disclosures, originally submitted for possible patent applications, but now released from such action. (For further details, see article entitled "Project: Use It" presented in this issue.) Research Needs and Speculative Ideas will, in general, be dependent for material on letters from our readers containing specific statements of problems which await further clarification or solution, or imaginative ideas that require further development. The name and organization of the reader submitting suggestions or comments will not be published without his express consent.

If the reader so desires, he is free to also submit the application suggestion appearing in his letter in the form of a proposal request for funds to support the implementation of the suggestion.

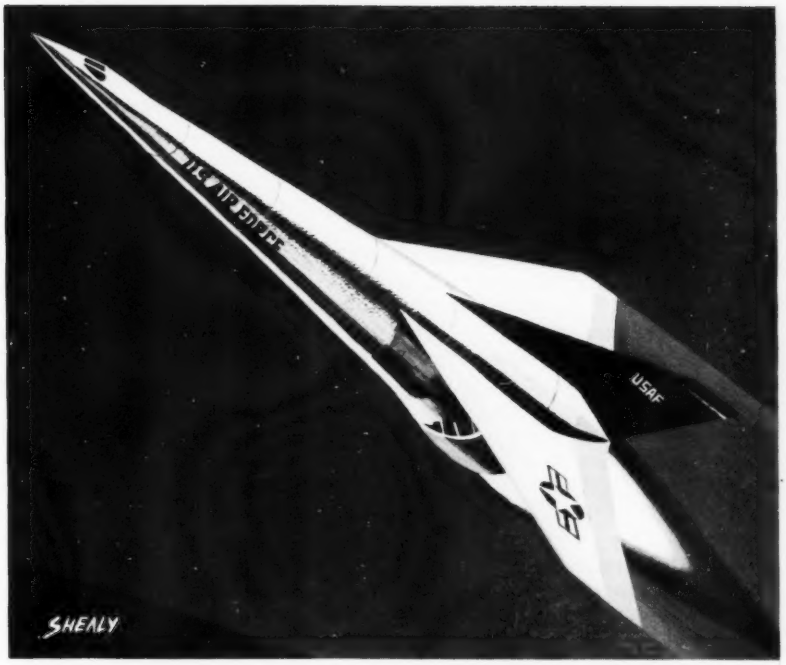
The R&D Interaction Directorate would like to be informed of any action stimulated by this new Reader's Interchange. Suggestions for its improvement are also welcome.

Headquarters Office of Aerospace Research (PGRO)
1400 Wilson Boulevard
Arlington, Virginia 22209

table of contents

HIGH SPEED COMBUSTION MECHANISMS FOR SUPERSONIC COMBUSTION RAMJETS	1	Dr. Bernard T. Wolfson, Directorate of Engineering Sciences, AFOSR
INTERFEROMETRIC MEASUREMENTS OF MATERIALS UNDER HIGH PRESSURE	4	Dr. D. W. Langer and R. A. Montalvo, Solid State Physics Research Laboratory, ARL
EARTH MODELING	7	Lt Col Durward D. Young, Jr., Directorate of Physical Sciences, AFOSR
THE MATHEMATICAL THEORY OF QUANTUM FIELDS	10	Dr. Irving Segal, Massachusetts Institute of Technology
ABSOLUTE AND CONVECTIVE PLASMA INSTABILITIES	13	Dr. A. Garscadden and Dr. P. Bletzinger, Plasma Physics Research Laboratory, ARL
A LOOK AT "ROBIN" (ROCKET BALLOON INSTRUMENT) AFTER TEN YEARS OF DEVELOPMENT	15	Aerospace Instrumentation Laboratory, AFCRL
HYPERSONIC TURBULENT BOUNDARY LAYERS	16	Dr. Anthony W. Fiore, Hypersonic Research Laboratory, ARL
NONLINEAR OPTICS AND FAR INFRARED RADIATION	19	Dr. Fielding Brown, Physics Dept., Williams College
SOME EXPERIMENTAL RESULTS OF AN EXTREMELY LARGE AREA RATIO INJECTOR SYSTEM	22	K. K. Joshi, Systems Research Laboratories, Inc., Dayton, Ohio
EXTENDING THE LIFETIME OF RUBY LASERS	23	Optical Physics Laboratory, AFCRL
TRANSMITTING VOICE SIGNALS MORE EFFICIENTLY	24	Data Sciences Laboratory, AFCRL
THE SNAP-SHOOT GUNSIGHT	26	Directorate of Aerospace-Mechanics Sciences, FJSRL
VARIATIONS IN SOLAR ULTRAVIOLET RADIATION THROUGH A COMPLETE SOLAR CYCLE	28	Aeronomy Laboratory, AFCRL
SURFACE PHYSICS DEPARTMENT OF THE CAVENDISH LABORATORY, UNIV. OF CAMBRIDGE, ENGLAND	29	Lt Col R. Boverie, EOAR
STATISTICAL PREDICTION OF SOLAR FLARES	31	Space Physics Laboratory, AFCRL
IONIZATION EXTREMES AT ROOM TEMPERATURES	32	Space Physics Laboratory, AFCRL
SCINTILLATION DATA AND SATELLITE COMMUNICATIONS	33	Ionospheric Physics Laboratory, AFCRL
PROJECT: USE IT (Undeveloped Scientific Exploitation of Inventions and Technology)	35	Lt Col Ludwig Lippert, Staff Judge Advocate, OAR
READER'S INTERCHANGE	36	
Research Advances	37	
Research Needs	38	
Speculative Ideas	38	
Invention Disclosures	38	

high speed combustion mechanisms for supersonic combustion ramjets



DR. BERNARD T. WOLFSON
Directorate of Engineering Sciences, AFOSR

The full realization of the high performance potential of supersonic airbreathing powerplants has long been a matter of great interest to the United States Air Force in connection with the technology of very high speed aircraft. In the current generation of aircraft, the most effective powerplants are the turbojets and turbofans. These engines depend on subsonic combustion chambers which must be fed a stream of high pressure and very low speed air by the compressor and diffuser, so that combustion of the injected liquid fuel spray can be completed within the combustor cannister. Subsequently, the combustion products are expanded through the turbine to drive the compressor and accessories, and then through the exhaust nozzle to produce the desirable thrust.

At very high speeds (Mach 4 and greater) these power systems present formidable problems on rotating components, in addition to those problems due to the high temperatures experienced by the engine structure (both rotating and nonrotating). Therefore, it is not surprising that a great deal of interest has been focused on the ramjet engine which conceptually is nothing more than a variable area duct. This concept immediately eliminates the need for rotating components, thus simplifying those problems to a large degree. The thermodynamic cycle of the ramjet engine consists of air compression in the inlet, heat addition in the combustion, followed by expansion of the combustion products in the exhaust nozzle. The ramjet engine is potentially capable of operating over wide ranges of conditions–subsonic, supersonic, and hypersonic. However, the supersonic combustion ramjet (SCRAMJET) concept becomes most attractive in the flight regime above Mach 4.

The principal obstacle, anticipated by early workers in the supersonic combustion field, was the shortness of the fuel residence time in the combustor section compared to the fuel-air mixing time and the mixture combustion time. This apprehension stemmed in part from the low rates of laminar flame propagation observed for non-detonative combustion of gaseous fuel mixtures such as hydrogen-air (10 ft/sec), acetylene-air (5 ft/sec), ethane-air (1.5 ft/sec), and so on down.

About a decade ago, in view of the great need for information, the Air Force Office of Scientific Research, with General Applied Science Laboratory (GASL), instituted a program of fundamental theoretical and experimental studies of the mechanisms and phenomena associated with supersonic combustion (Contracts F44620-68-C-0045 and 69-C-0056), initially under the direction of Dr. A. Ferri and now under the guidance of Drs. S. Slutsky and R. Edelman.

One of the first results of this program was an experimental verification of supersonic combustion produced by injecting hydrogen gas into an airstream traveling approximately 10,000 ft/sec. Pressure measurements along the wall of the tunnel showed that the reactions were completed in short distances of the order of 1 to 2 feet (1).

At the same time, Libby, Visich, Pergament, and Bloom (2,3,4), succeeded in preparing a digital computer program in which the rate constants for the elementary gas reactions obtained by the physical chemists (e.g., Duff, Schott, Fine, Kinsey, Nicholls) could be input to obtain

overall ignition delay times and combustion times for homogeneous gas mixtures. These delay times were in essential agreement with the tunnel experiments.

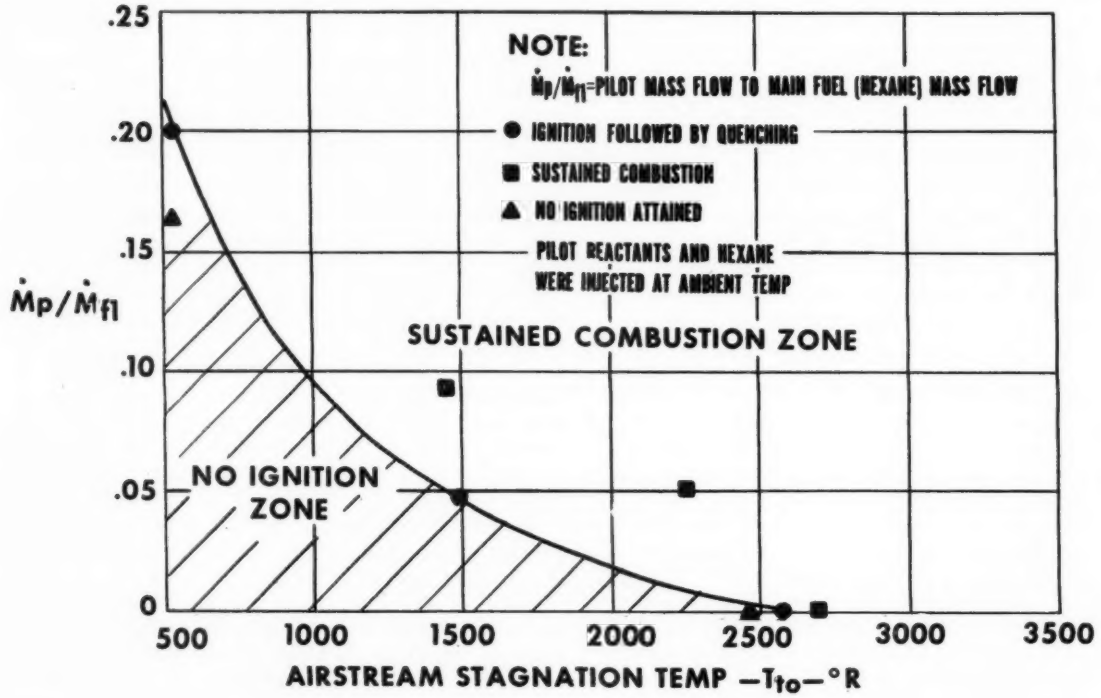
With the greater availability and flexibility of large scale digital computers, programs were developed which could treat steady-state two-dimensional (and axisymmetric) combustion and mixing, including diffusion, heat conduction, viscosity, and finite rate chemistry for the hydrogen-air system. Lateral pressure gradients, however, were neglected. The inclusion of finite rate chemistry with seven species (H_2, O_2, O, H, OH, H_2O, and N_2) resulted initially in numerical problems of considerable difficulty. Thus, when the Runge-Kutta, or predictor-corrector integration step sizes, were not exceedingly small, it was found that the concentrations of the reactive species, O, H, OH, and H_2O, underwent violent numerical oscillations that rendered the results meaningless. The mathematical nature of this difficulty was recognized by Moretti (5) and was effectively removed by using more appropriate integration procedures (6,7).

These finite rate chemistry calculation procedures were then extended to such hydrocarbons as methane through propane (8) (involving 69 reactions and 31 chemical species). By use of approximations in the hydrocarbon breakdown, it was possible to deal with rocket nozzle flows in which kerosene was used as a fuel. Excellent experimental confirmation was obtained (9). The approximations were chosen to give rise to the same ignition delay and combustion times as were obtained previously in more formal studies of propane oxidation. Similar excellent agreement was obtained for internal mixing and combusting flows, such as occur in engine ducts (10,11).

The above studies reflected the preoccupation of researchers in high speed airbreathing combustion systems with purely gas phase systems. An important finding of the studies was that the chemical reaction rate characteristics were not necessarily the controlling parameters, but rather that the system which described the observed behavior was a basic coupling of chemical, heat conduction, molecular and free radical diffusion, and turbulent viscosity momentum transfer mechanisms.

Success was obtained in expressing these mechanisms mathematically and in explaining and predicting many important combustion flow fields of practical interest. In particular, the concepts, which were developed and which could be modeled on a digital computer, led to the clear demonstration that hydrogen could be burned in a combustor of length short enough for practical purposes (12,13), and that hydrocarbon gas phase reactions could be realistically represented.

Meanwhile, the urgency of the storable hydrocarbon-fueled engine for high speed Air Force application has led



MINIMUM MASS FLOW REQUIREMENTS FOR IGNITION OF INJECTED LIQUID HEXANE

$M_\infty \approx 2$, $P_\infty \approx 1$ ATM AND PILOT $\phi_p \approx 0.19$, $\dot{M}_p \approx .005-.016$ lb/sec

Figure 1.

to the development of "flight-type" pilot and combustor systems for use with vaporized liquid fuels of the JP type. These systems, which owe a great deal of their conceptual philosophy and operational design to the fundamental studies sponsored by AFOSR, can operate efficiently over a wide range of engine flight speeds, i.e., of inlet air temperature and pressure.

During the last 18 months, a further step in high speed airbreathing engines was taken by GASL with the extension of the problem to include the effects of multiphase mechanisms on the high speed combustion process. The program started with the direct injection of liquid hydrocarbon fuel (hexane) into the air flow, without previous vaporization. The key concept, relied upon for rapid mixing of liquid fuel with the oxidizing atmosphere, was the expectation that the large resultant Weber numbers (ratio of surface shear to surface tension forces) would produce rapid breakup of the droplets. This type of behavior is clearly observed in the shattering of droplets on passage through a strong shock. The transition of the droplet to a region of ambient gas flow velocity, markedly different from the initial particle velocity, is analogous to the transition occurring upon normal injection of the liquid fuel jet from the wall or strut into a high speed air stream.

During the work of the last 18 months, it was found that the conditions of spray formation, residence time, and the local thermodynamic state could be controlled to obtain ignition and stable combustion of liquid hydrocarbon fuels injected directly into a supersonic air stream.

The results were that reliable hexane autoignition was obtained for air flowing at Mach 2 with stagnation temperatures of 2600°R or more, using both wall and central injectors, followed by intense combustion and heat release (14). More recently, experiments carried out, using a central injector with a hydrocarbon pilot (ethylene-0_2 combustion products), resulted in stable piloted ignition and combustion for air temperatures ranging from autoignition (2600°R) down to ambient (530°R). In addition, measurements made in the facility showed rapid heat release, with apparently high combustion efficiencies, of the order of that predicted for an ideal one-dimensional heat release process. This was achieved with total pilot-to-main fuel mass flow ratios of 20 percent or less (Figure 1).

These exploratory experiments imply that, from a practical point of view, liquid storable fuels, such as hexane or the JP fuels, may be as effective a fuel in high speed combustion as pure hydrogen, and of course much more convenient because of their storability.

However, the foregoing work with liquid hexane as a fuel is only a part of the area of multiphase mixing and reaction which must also include consideration of such fuels as slurries which give rise to 3-phase (gas-liquid-solid) systems. With this in mind, GASL will next concentrate on studies with magnesium-hexane slurries, including investigation of the gross sequential behavior of the hexane combustion and evaporation followed by the metal oxidation phase.

Results obtained from the GASL work have already added considerably to the fundamental understanding of supersonic combustion phenomena and have contributed immensely to the formulation of a sound basis for the design of a practical supersonic combustion engine. Indeed, due to the research activities of the GASL team and other scientists working in this area with the support of AFOSR, the birth of a new and exciting type of propulsion engine is fast approaching reality. This supersonic combustion engine will be practical and efficient, and will contain desirable features from both military and commercial viewpoints; it will be capable of wide ranges of operation–from relatively low supersonic speeds to hypersonic speeds up to and including escape velocity, and from low to extremely high altitudes.

Contact: Dr. Bernard T. Wolfson
Telephone Extension 45565

REFERENCES

(1) Tamagno, J. and O. Lindemann, "Experimental Results of Supersonic Combustion," *GASL TR 322*, December 1962.

(2) Libby, P. A. and M. Visich, Jr., "A Theoretical Analysis of the Turbulent Mixing of Reactive Gases with Application to the Supersonic Combustion of Hydrogen," *GASL TR 226*, April 1961.

(3) Libby, P. A., "A Theoretical Analysis of the Turbulent Mixing of Reactive Gases with Application to the Supersonic Combustion of Hydrogen," *GASL TR 242*, June 1961.

(4) Libby, P. A., H. S. Pergament and M. H. Bloom, "A Theoretical Investigation of Hydrogen-Air Reactions, Part I–Behavior with Elaborate Chemistry," *GASL TR 250*, August 1961.

(5) Moretti, G., "A New Technique for the Numerical Analysis of Nonequilibrium Flows," *AIAA Journal*, Vol. 3, No. 2 (February 1965), 223-229.

(6) Magnus, D. E. and H. S. Schechter, "Analysis of Error Growth and the Stability for the Numerical Integration of the Equations of Chemical Kinetics," *GASL TR 607*, June 1966.

(7) Magnus, D. E. and H. S. Schechter, "Analysis and Application of the Pade Approximation to the Integration of Chemical Kinetic Equations," *GASL TR 642*, (AD 819 093) March 1967.

(8) Chinitz, W. and T. Baurer, "An Analysis of Non-Equilibrium Hydrocarbon-Air Combustion," presented at Meeting of the Western States Section/The Combustion Institute, Santa Barbara, California, October 25-26, 1965.

(9) Edelman, R. and O. Fortune, "A Quasi-Global Chemical Kinetic Model for the Finite Combustion of Hydrocarbon Fuels with Applications to Turbulent Burning and Mixing in Hypersonic Engines and Nozzles," *Preprint No. 69-86*, presented at the AIAA 7th Aerospace Sciences Meeting, January 20-22, 1969.

(10) Edelman, R. and O. Fortune, "An Analysis of Mixing and Combustion in Ducted Flows," *Preprint No. 68-114*, presented at the 6th AIAA Aerospace Sciences Meeting, January 22-24, 1968.

(11) Edelman, R. and G. Weilerstein, "A Solution of the Inviscid-Viscid Equations with Application to Bounded and Unbounded Multicomponent Reacting Flows," *Preprint No. 69-83*, presented at the 7th AIAA Aerospace Sciences Meeting, January 20-22, 1969.

(12) Slutsky, S., J. Tamagno and N. Trentacoste, "Supersonic Combustion in Premixed Hydrogen-Air Flows," *AIAA Journal*, Vol. 3 (2 September 1965) 1599-1665.

(13) Ferri, A., S. Slutsky and G. Moretti, "Mixing Processes in Supersonic Combustion," *J. Soc. Indust. Appl. Math.*, 13 (1965), 229-258.

(14) Slutsky, S., F. Williams and J. Tamagno, "Ignition and Combustion of Liquid Hydrocarbon Fuels in Supersonic Flows," *GASL TR 724* (AFOSR-69-139TR), June 1969.

DR. D. W. LANGER AND R. A. MONTALVO
Solid State Physics Research Laboratory, ARL

interferometric measurements of materials under high pressure

Visible and infrared detection devices and high frequency oscillators connected to radar and communication equipment all make use of II-VI compound semiconductors. To improve the quality of these devices, further research was needed to complement work performed earlier by the Solid State Physics Research Laboratory on the change in the electronic properties of semiconductors at high pressures. Therefore, this laboratory undertook a study of the compressibilities of these semiconductors, choosing the interferometric method as the one that seemed especially useful, particularly when uniaxial crystals such as CdS are involved.

Thus, a Fabry-Perot interferometer, which could be used inside an optical pressure chamber, was constructed to compare the length change of semiconductors with the well-known length change of iron. Pressure is applied by means of liquids or gases. Figure 1 shows the arrangement.

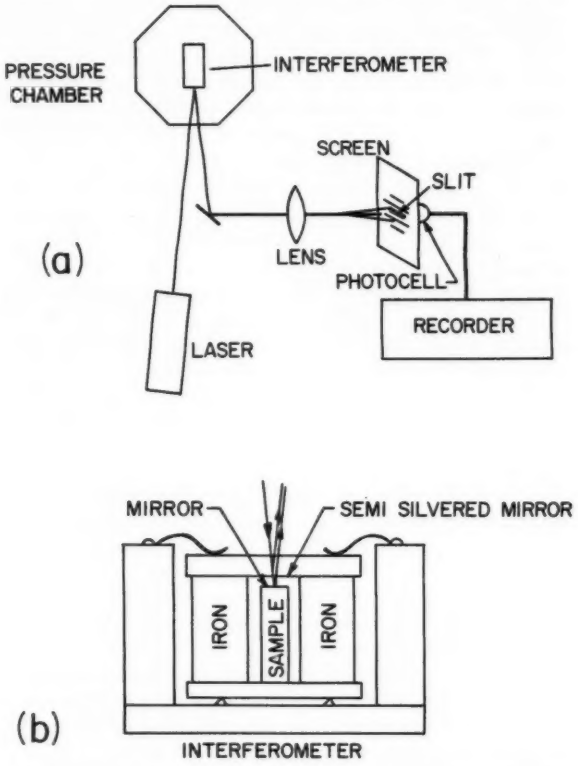


Figure 1. (a) Experimental setup for measuring the compressibility of crystals at high pressures. (b) "Blowup" on the interferometer assembly. S is a semisilvered glass surface and M is the fully-silvered surface of the sample.

Light from a He-Ne laser is transmitted through the pressure window where it is partly reflected from the first semisilvered mirror. The part that is transmitted through the pressure window is reflected from the silvered front surface of the sample. Both reflected beams form interference fringes on an external screen with a slit and photocell.

The order of the fringes depends on the length of the optical path between the two silvered surfaces. When pressure is gradually applied, the difference of the length change of the iron spacer and the semiconductor sample produces a length change of the space between the mirrors. Thus, every time a change of one fringe occurs on the screen, it indicates a gap change in length of $\lambda M/2$, where λ is the wavelength of the laser light (6328 Å) and M is the refractive index of the pressure fluid. In the experiment, we counted the number of fringes that passed a reference point when the pressure was changed from 1 atmosphere to 10,000 atmospheres.

The pressure dependence of the index of refraction of the pressure fluid, which had to be known in order to compute the compressibility, was unknown for suitable fluids. After trying isopentane and mesitylene, isopentane was chosen because of its high solidification point and because of the similarity of its index of refraction to the glass which formed the substrate of the semi-silvered surface (thus reflections from the front surface of this glass were eliminated).

A separate experiment, devised to measure the index of refraction of isopentane as a function of pressure, was set up by removing the sample from the interferometer, and using only the iron spacer with a mirror on the other side of the iron. Figure 2 shows the results obtained for isopentane.

The data was analyzed in terms of Bottcher's equation:

$$\frac{n^2}{(n^2-1)\ (2n^2+1)\ V} = \frac{M}{12\pi N}\left[\alpha^{-1} - \frac{1}{a^3}\left(\frac{2n^2-2}{2n^2+1}\right)\right]$$

where M is the molecular weight; V, the specific volume; N, Avogadro's number; α, the polarizability; and a, the effective molecular radius. As a by-product, this equation furnished the values for the polarizabilities, $\alpha = 8.77$ Å and 14.8 Å, and the effective ionic radii, $\alpha = 2.76$ Å and 3.24 Å, for isopentane and mesitylene, respectively.

The linear compressibility of the sample in our experimental setup is given by:

$$K = K' + \frac{m\lambda/2 - L(n_2 - n_1)}{n_2\ (P_2 - P_1)\ t}$$

where K′ is the known compressibility of iron which is

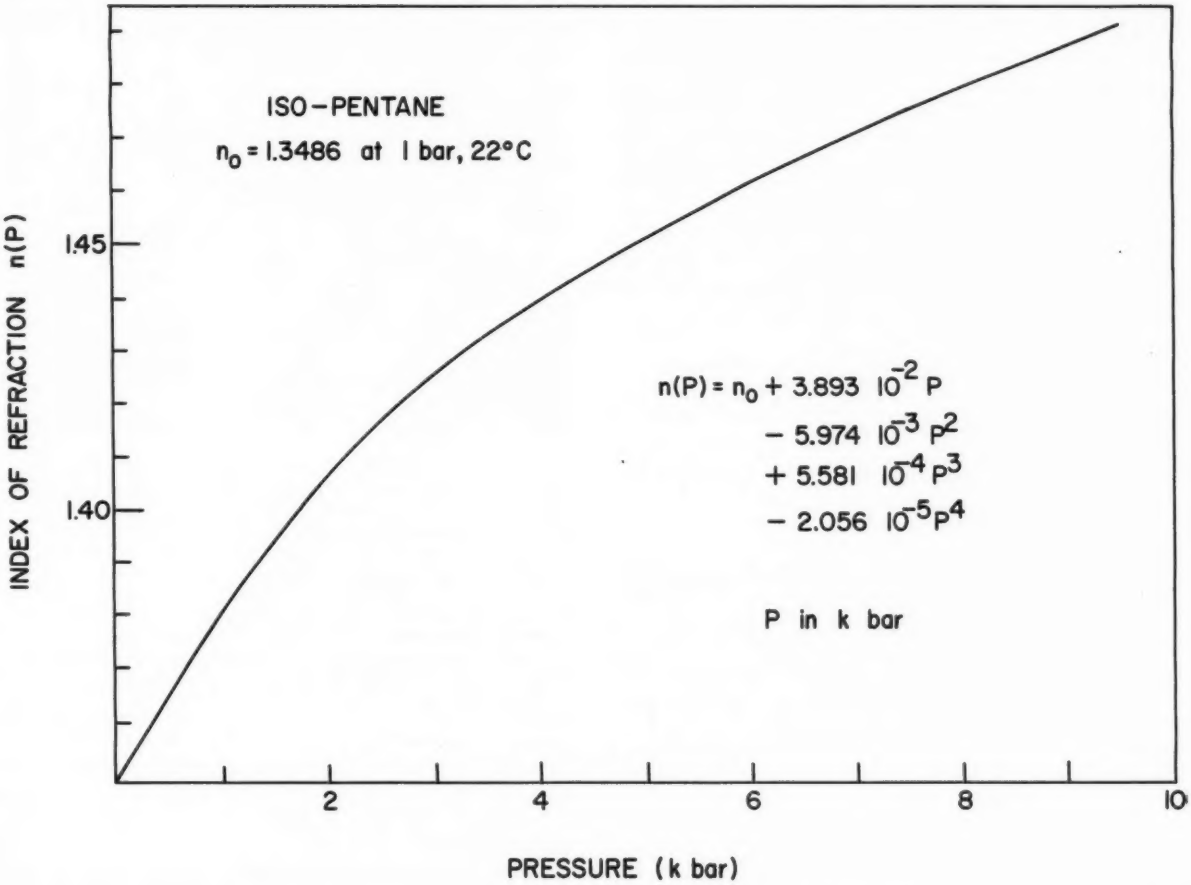


Figure 2. Pressure dependence of the index of refraction of isopentane.

(1.99×10^{-7} bar^{-1}); t is the length of the sample; L is the initial length of the gap; m is the number of fringes counted between the initial and final pressures, P_1 and P_2; and n_1, n_2 are the initial and final values of the refractive index of the fluid.

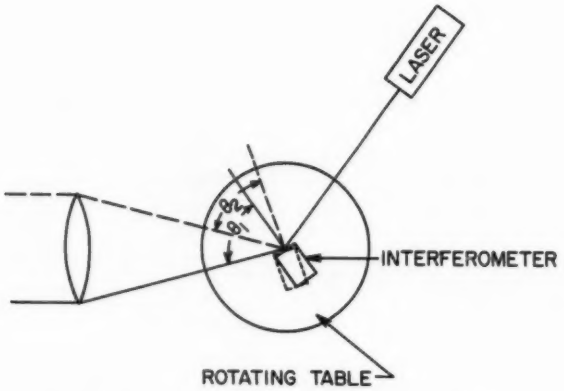


Figure 3. Apparatus arrangement for measuring a small interferometer gap.

A novel method was devised to measure the gap L. The interferometer was placed so that the gap was at the center of a rotating table, see Figure 3. A lens was placed so that its focal point coincided with the axis of rotation of the table. As the table rotates between the limits θ_1 and θ_2, the laser beam is directed to the same point on a screen far from the lens. The changing difference in the path lengths for the two light beams when the table is rotated produces motion of the fringes at the screen. The relation is the usual Bragg formula, $2i\cos\theta = m'\lambda$. If the fringes are counted between the angles θ_1 and θ_2 the gap length will be given by:

$$l = \frac{m\lambda}{2(\cos\theta_2 - \cos\theta_1)}$$

where λ is the wavelength of the laser light and m is the number of fringes counted. Due to the spherical aberration of the lens, the beam was not completely stationary at the screen. An accurate count of the fringes can still be made if the interferometer is rotated so that the fringes move in the vertical direction while the beam moves horizontally.

Finally, knowing all the constants in the equation, we were able to derive the compressibilities of our samples; they are listed in table 1.

Table 1

LINEAR COMPRESSIBILITY OF SAMPLES

$\frac{1}{L}\frac{\Delta L}{\Delta P}$ · (IN 10^{-7} bar^{-1})

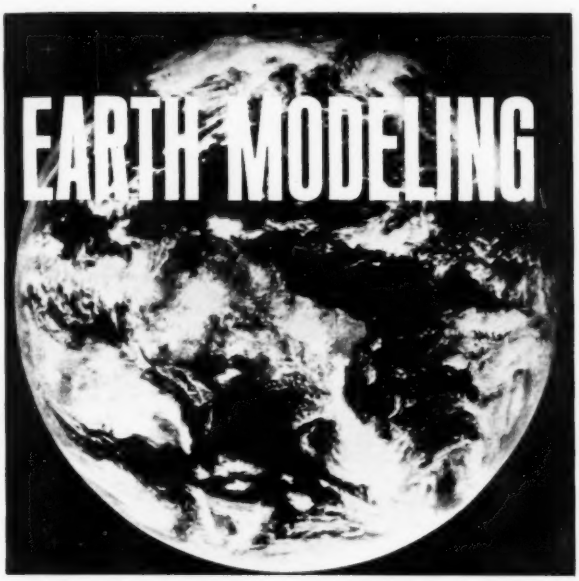
CdS ⊥	5.31	CdTe	7.62
CdS ∥	5.20	ZnS	4.27
CdSe ⊥	6.28	ZnSe	4.92
CdSe ∥	5.85	ZnTe	6.47
ZnO ⊥	2.21		
ZnO ∥	2.49		

Contact: Dr. D. W. Langer
Telephone Extension 54702

Dr. Dietrich Langer has been a Senior Physicist in the ARL's Solid State Physics Research Laboratory since September 1957. His chief effort is in experimental and theoretical research on the properties of the band structure of II-VI compounds, with emphasis on the extrema in the energy-wave vector diagram. Coefficients of temperature and pressure, obtained from the effects of these parameters on the reflectivity of a crystal, are compared to deduce the explicit broadening of the band due to the temperature excitation of scattering modes. His work also includes the study of the changes in electronic spectra of transition and rare earth metal ions in crystals induced by changes in the crystalline field.

After graduation from Canisius Kolleg in Berlin in 1950, he attended the Technische Universitat, Berlin, receiving the Diplom-Ingenieur (equivalent of an M.S.) in 1957 and later his Ph.D. in 1960 while working at ARL. He pursued further studies in Applied Physics at Harvard University while on leave from ARL in 1961. In 1964-1965 he engaged in postdoctoral studies at the Physics Department of the Ecole Normale Superieure, a branch of the University of Paris.

Dr. Langer is a member of the American Physical Society. He has regularly presented papers on his work at various national and international scientific conferences and has published more than 30 articles in scientific journals.



LT COL DURWARD D. YOUNG, JR.,*
Directorate of Physical Sciences, AFOSR

The planet Earth on which man currently lives is for the moment, in expression and in fact, our whole world. With the exception of our single satellite, we have only limited data from remote sensing probes to furnish clues for conjecture about the nature and composition of other planets in the universe. Man's superficial attempts to probe, measure, and observe the physical character of the earth preceded the acquisition of data on other planets by many decades. Yet the deepest probes, which have penetrated less than 9 km of the 6,340 km distance to the earth's center, have not even reached to the base of the crust that lies another 35 km deeper on most continental masses.

Physical measurements and observations have been confined to laboratory and field measurements of the properties of the rocks which are accessible at the surface or obtained from drill holes. Information about the structure, composition, and state of the remaining 95% of the earth must be gleaned from remote sensing, and then astute interpretation must be made of the observed data.

Some of the readily and commonly measured physical parameters of the earth include temperature, density, magnetic susceptibility, conductivity, and elasticity. Of these, the last has thus far proved to be most useful, since it is possible to use this quality to measure the velocity of seismic energy propagating through the earth from a known transducer source (shotpoint or earthquake) to an accurately located receiver. When an explosive charge is used, the time of detonation can easily be determined to millisecond accuracy. Research in the earth sciences in the last four decades have been heavily dependent on seismic methods for both commercial exploration and for academic research.

As with most sciences, there are several methods and combinations of methods by which investigations are conducted, i.e., laboratory, theoretical, and field. In the science of studying the earth, probably best referred to as geology, the earth itself is a ready laboratory. The problem is to discover the most effective method for performing the investigations.

Consider for a moment the laboratory method. Available are bits and pieces of rocks and minerals which have been obtained only from the skin or crust. Even with these samples, it is presently impossible to duplicate in the laboratory the conditions under which they were formed and existed. The elusive environmental factors are primarily heat and pressure. From these rock fragments, the laboratory-derived equations of state are computed and inferences are drawn about conditions which may exist at the crust-mantle interface and in the upper mantle. At present this information cannot be extrapolated deeper than 44 km with any confidence.

Theoretical methods, essentially the subject of this article, can be no better than the physical data provided by laboratory and field measurements. A major goal of field methods in geophysics (seismology) is to uniquely specify the distribution of the two elastic velocities (compressional and shear modes) and density with depth in the earth and to relate these distributions to variations in composition, phase, and temperature in the earth's interior. While it has not been proven in the mathematical sense that a unique solution can be obtained, Backus and Gilbert (2) have shown that under certain circumstances stable weighted averages of these parameters as a function of depth can be calculated. Complications arise because the data set for recovering earth structure are inprecise and incomplete, and the laboratory and theoretically determined equations of state for interpreting elasticity and density distributions are tentative.

Despite these difficulties, it still seems possible, even with the presently available data, to make some meaningful statements about the earth's interior. Research supported by the Air Force Office of Scientific Research, at the Massachusetts Institute of Technology, under the direction of Dr. Frank Press, bas explored this possibility, using the best and most recent field, laboratory, and theoretical data in a Monte Carlo inversion procedure which uses random selection to generate large numbers of earth models in a computer. Each generated model is tested against real geophysical data; only those models are retained whose properties fit the data within prescribed tolerances. The method offers the advantage that reasonable models are found without bias, preconceived ideas, or uncertain assumptions of equations of state or composition. If a large number of models can be efficiently examined, the retained models can be considered as representative of successful models that fit the field data. When the models fall into a narrow band, geophysically meaningful conclusions can be drawn despite the inability to specify a unique model.

The computation technique uses an IBM 360-65 computer which stores the physical data [compressional velocity, shear velocity, density, and Bullen's (4) seismic

*Col Young's present assignment is Chief, Underground Test Branch, Radiation Division, Air Force Weapons Laboratory, Kirtland AFB, New Mexico.

travel times], varies the velocity by a power law in each layer, and randomly generates literally millions of models. As each model is generated, it is tested against a permanently stored table of variational parameters (7) which tests the perturbation of the eigenperiods due to velocity, density, or core radius variations. This test is made after the selection of density and velocity models. The velocity models are selected to eliminate early in the process those models which cannot be brought into agreement with eigenperiod data by density perturbations. Each density model is further tested against data for the mass and moment of inertia of the earth. A key requirement of the Monte Carlo method is that the selection procedure must produce an unbiased, representative group of models for examination. Figures 1, 2, and 3 show a run in which 25 models were generated by passing tests made against known geophysical data. Note that the velocity and density space between the permissible bounds is nearly uniformly filled. Since millions of earth models were generated and examined to produce these models, it would be surprising if continued operation of the program would produce a successful model significantly different from these.

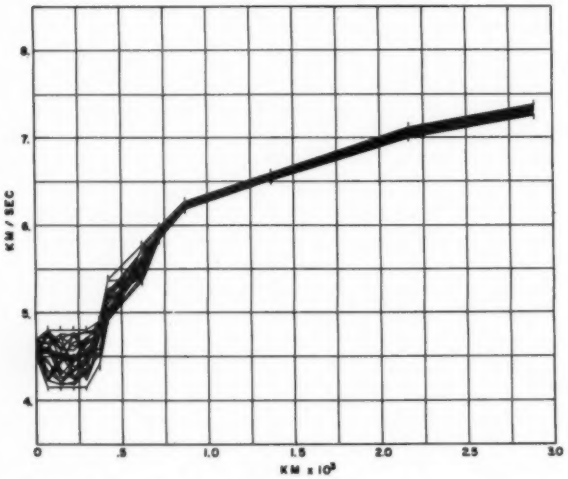


Figure 1. Twenty-five shear velocity models of the mantle not subjected to geophysical constraints to test distribution of randomly generated models.

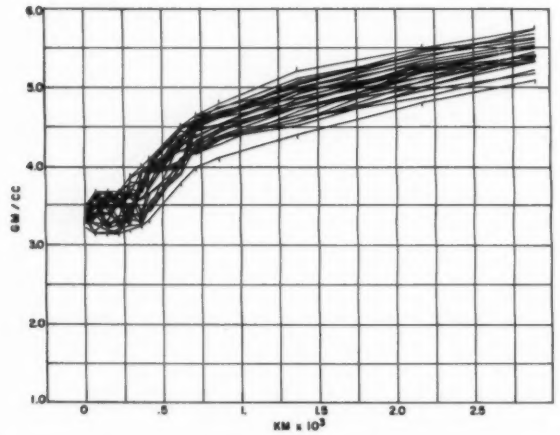


Figure 2. Unconstrained mantle densities (see Figure 1 caption).

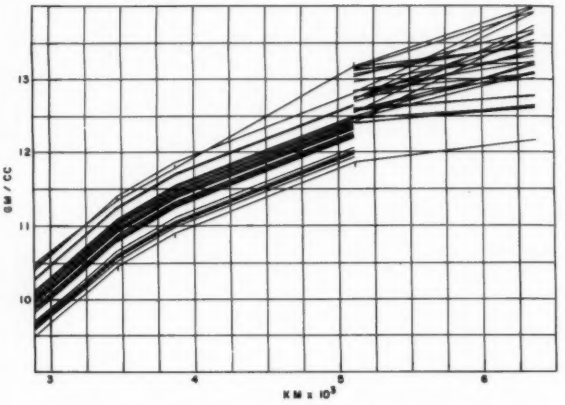


Figure 3. Unconstrained core densities (see Figure 1 caption).

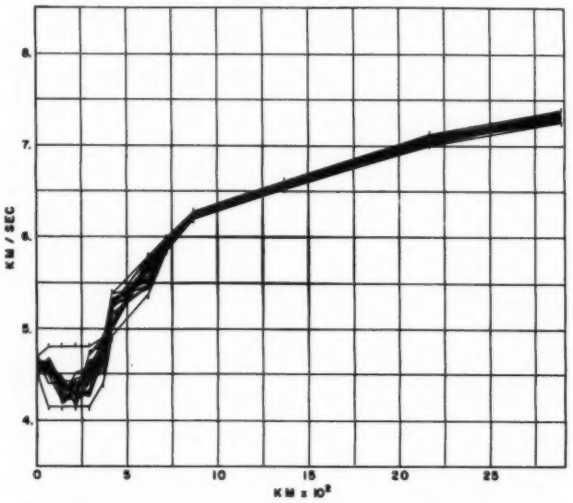


Figure 4. Twenty-seven successful shear velocity models for the mantle. Ticks on upper and lower bounds show where parameter was randomly varied.

RESULTS

The Upper Mantle Under Oceans: Without exception, every successful model contains a low velocity zone for shear waves that occur at depths between 150 and 250 km. If the top layer of this zone is characterized by a shear wave velocity greater than 4.5 km/sec, then its thickness is between 50 and 100 km. It was impossible to find a single model without a low velocity zone, in spite of a special search in which 162,000 monotonic shear velocity models were examined. A low velocity zone seems required by the MIT data, since almost every possible model without it was examined and eliminated. This low velocity zone is prob-

ably due to partial (grain boundary) melting.

The Transition Zone: Seismic array data have been used recently to establish rapid velocity changes at depths near 400 and 700 km. These field observations were incorporated into the model by fixing the compressional velocity and narrowing the range of permissible shear velocities at these depths to conform to the rapid increases (Figure 4). Although no such restrictions were placed on the density values, a rapid increase in density across the transition zone is evident on all models (Figure 5). This increase is due to compression, to phase changes, and possibly to compositional changes. Such phase transitions have been deduced from laboratory observations of the olivine-spinel phase change at pressures corresponding to depths near 400 km and by theoretical and experimental indications for a post-spinel phase transition (1).

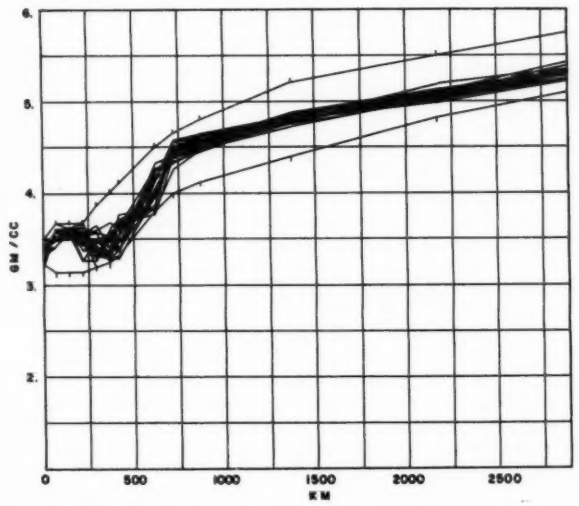


Figure 5. Density in the mantle (see Figure 4 caption).

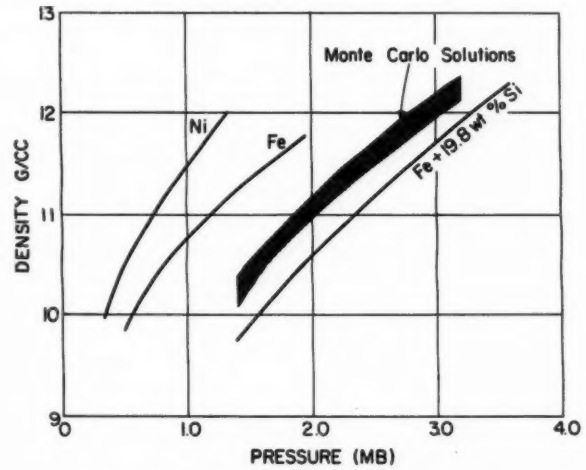


Figure 6. Band of core densities from successful models together with shock wave density data for Fe, Ni, and Fe + 19.8 wt. % Si.

The Lower Mantle: The results of the shear velocity and density models are shown in Figures 4 and 5. The results of the lower mantle model rest heavily on Fairborn's (5) independent determinations of a band of shear velocity distributions consistent with $dt/d\Delta$, and travel time data obtained at the Large Aperture Seismic Array (LASA) in Montana. The range of shear velocities permitted by Fairborn's results is quite narrow (Figure 4). It was therefore possible to use eigenperiod data to constrain the density in the lower mantle to a greater degree than before. The shear velocity envelope shows a higher gradient than has usually been assumed and thus required a compensatory reduction in the density gradient in order to fit the spheroidal eigenperiod data.

The Core: The assumption of adiabaticity in the fluid core and the constraints imposed by the data prescribe the densities to the surprisingly small range of .25 gm/cc. Using the laboratory shock wave data of McQueen and Marsh (6) and Bulchan and Cowan (3), it was observed that iron alloyed with a miscible, abundant element such as silicon (19.8 wt%) would account for the core densities. There is no control on the density in the inner core with the data used here. Changes in the core radius ranged from -3 km to +10 km. The core model is shown in Figure 6.

CONCLUSIONS

If the assumptions made in designing the models are correct, the following results appear to be reasonable:

1. There is a low velocity zone for shear waves in the suboceanic upper mantle.
2. There is a high density zone in the lithosphere near 100 km depth.
3. The rapid velocity increase near 400 km is associated with an olivine-spinel transformation.
4. The density at the top of the core is between 9.9 and 10.2 gm/cc.

Contact: Mr. William J. Best
Telephone Extension 45456

REFERENCES

(1) Anderson, D. L., "Phase Changes in the Upper Mantle," *Science*, 157 (1967), 1165.
(2) Backus, G. and F. Gilbert, "The Resolving Power of Gross Earth Data," *Geophysics, J.*, 16 (1968), 169.
(3) Balchan, A. S. and G. R. Cowan, "Shock Compressions of Two Iron Silicon Alloys to 2.7 Megabars," *Geophysics, J., Res.*, 71 (1966), 357.
(4) Bullen, K. E., "Seismic Ray Theory," *Geophysics, J.*, 4 (1961), 93.
(5) Fairborn, J. W., "Shear Velocities in the Lower Mantel," *Bull. Seismol. Soc. Am.*, Vol 59 (1969), 1983-2000.
(6) McQueen, R. G. and S. P. Marsh, "Shock Wave Compression of Iron-nickel Alloys and the Earth's Core," *Geophysics, J., Res.*, 71 (1966), 1751.
(7) Wiggins, R. A., "Terrestrial Variational Tables for the Periods and Attenuation of the Free Oscillations," *Physics of the Earth and Planetary Interiors*, 1 (1968), 201.

THE MATHEMATICAL THEORY OF QUANTUM FIELDS

(or exactly how is energy converted into mass, and vice versa?)

DR. IRVING SEGAL*
Massachusetts Institute of Technology

We may soon be in a position to wrap up, clearly and correctly, several centuries of development in the theory of light, matter, and their interaction. Although volumes of mathematical and physical theory would be required to give a complete and up-to-date account of the subject, the basic ideas of these sophisticated theories are remarkably simple from a conceptual standpoint. To some degree at least, the following sketch of the subject may be understood by the interested and educated layman.

Almost 300 years ago, Newton concluded that light was corpuscular rather than undulatory. Generations of school children have since been taught that Newton was in error and that visible light is part of a family that includes radio waves, X-rays, and other phenomena of an undulatory character. But mathematical equations supersede such anthropomorphic and philosophical questions. For light in empty space, or electromagnetic radiation in general, a theory now exists that is widely regarded as mathematically and physically complete. This theory combines the equations of Maxwell (developed in the last century) with bold intuitive developments by Dirac, Heisenberg, Pauli, and others in the 1920's. As now formulated in a mathematically unexceptionable way, it can be interpreted anthropomorphically as asserting that light, for natural and inevitable reasons, is both corpuscular and undulatory.

Maxwell's equations for light in a vacuum can be formulated mathematically as follows: the electromagnetic field has six components (three are electric, three are magnetic); they are the components of a second-order differential form ϕ in four-dimensional space-time. The equations assert, in terms of the calculus of differential forms in a Riemannian manifold, that

$$d\Omega = 0, \partial\Omega = 0$$

where the Riemannian metric in question is the indefinite one for which the fundamental metric form is

$$(dx)^2 + (dy)^2 + (dz)^2 - (dt)^2$$

at any point of space-time. Although expressed differently, Dirac's idea was to replace the components of the unknown function Ω (whose values in the Maxwell theory were ordinary real numbers representing field strengths) by ones whose values were operators in Hilbert space (or infinite matrices). (Figure 1)

This idea originated from Heisenberg's success in the much simpler case in which the momentum p and position q of an electron were replaced by operators. This kind of replacement is not unique, for there are many such matrices. Heisenberg achieved a type of uniqueness by making the simplest possible nontrivial assumption; namely, that in place of the relation $pq - qp = 0$, which would hold if p and q are classical quantities, he assumed that $pq - qp$ was such that it commuted with both p and q, without being identically zero. Actually, Heisenberg made the more specific assumption (emergent from work of Lie and Born) that $pq - qp = -i\hbar I$, where $\hbar$ denotes Planck's constant divided by 2π, and I denotes the unit matrix. This assumption is in essence implied by the apparently more limited assumption first indicated.

To keep his theory from being too general, Dirac essentially assumed that if f and g are components of the field strength at any two points of space-time, then the following was true: the so-called "commutator" of f and g (i.e., the operator $fg - gf$) was assumed to commute, i.e. have a vanishing commutator, with all components of the field strength at all points. Actually, Dirac, like Heisenberg, made a more specific assumption which follows from the more limited one indicated, together with the assmption of relativistic invariance, i.e., conformity to Einstein's special theory of relativity. This is a natural assumption to make, not only because of its empirical validity, but also because Maxwell's equations are relativistically invariant, and the emphasis on this invariance (due to Lorentz and Poincare) was one of the most important influences in Einstein's work.

*Dr. Segal's research in applications of global analysis to modern theoretical physics receives partial support from the Mathematical Sciences Directorate of AFOSR. This research has contributed significantly to a variety of results, including qualitative breakthroughs which have established the relevance and technical accessibility of problems of substance and sophistication which would have seemed hopelessly remote a few years ago. Dr. Segal's contributions to the understanding of physical phenomena are important to future advances and applications in areas such as radiation physics, elementary particles, and plasma physics; they also provide mathematical results applicable to problems in other fields such as fluid mechanics.

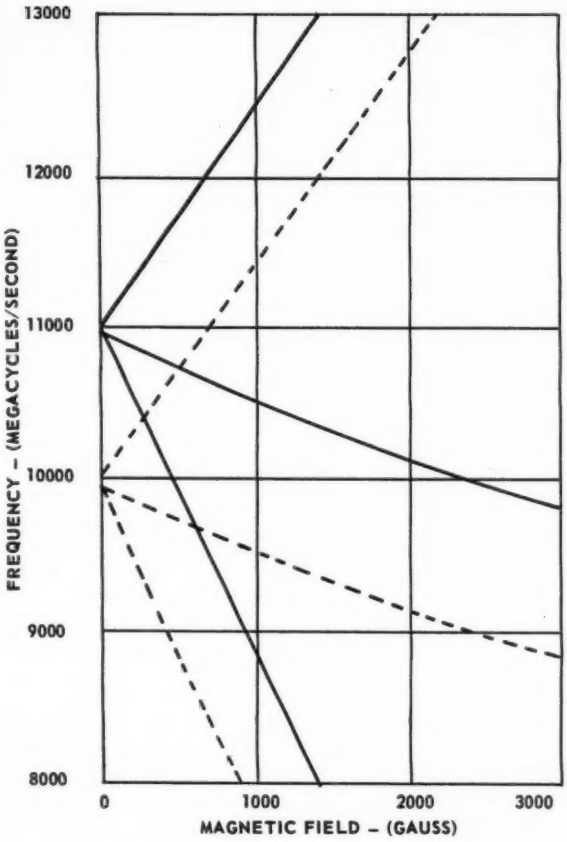


Figure 1. Experiment vs. Theory. The Lamb-Rutherford work in 1947 indicated for the first time the measurability of nonlinear quantum-field-theoretic effects. The discrepancy between the solid (theoretical) lines and the dashed (empirical) lines revealed the inadequacy of the earlier, more classical, quantum-mechanical theory.

The physicists erred in thinking that they were dealing with a unique well-defined theory as soon as they had specified the partial differential equation in question, and had made the assumption of the "canonical commutation relations" (those just indicated) together with relativistic invariance, for mathematical analysis has shown there are many such distinct theories. But they were partially right, for with one additional assumption which they tended to make implicitly, if not always explicitly, there really exists only one solution to the mathematically precise form of the Dirac-Heisenberg-Pauli extension (or so-called "quantization") of Maxwell's equations. The assumption is that the "energy" is positive. However, the energy had to be given a quite drastic theoretical reinterpretation in mathematical terms in order to arrive at a cogent and meaningful assumption.

Still, with all its mathematical crudity and vagueness, the Dirac radiation theory managed to explain an important question begged by the very success of the Bohr orbit theory a few years earlier. The Bohr theory could tell rather well the frequency of the light absorbed or emitted by electrons in certain circumstances; but it lacked an explanation of *why* the light should be emitted or absorbed. A computation of the first-order implications of the Dirac theory showed good agreement with observation as well as with phenomenological theory, on the matter of the transitions from one state to another. Despite its vagueness, the theory, as it developed at the hands of many theoreticians, came to have a definite architectural beauty of a mathematical sort. There were just two closely related difficulties: (1) the second-order and all higher-order implications of the Dirac et al. theory appeared persistently to be identically infinite; and (2) a close examination of the putative mathematical basis of the theory seemed to show that this basis did not, and indeed could not, exist without a wholesale mathematical reformulation of its basic concepts.

This basically infinite-ambiguous aspect of the mathematical theory of the creation and emission of light persisted for about four decades. The difficulty was more than a purely mathematical or physical one because the fundamental "quantized" Maxwell-Dirac equations for the interaction between light and matter were without really definite meaning. This made it impossible to show either that a solution did or did not exist. Most physicists thought that more experiments would be required to arrive at a new theoretical formulation without infinities. They were of many opinions; one famous man is reported to have argued that the difficulty arises from the odd number of fundamental physical infinities, which precluded their canceling each other out; others argued that the infinities arise from wrong conceptions of space and time, and that, e.g., space should be discrete, etc.

We are still far from being out of the woods, but it looks as if the purely mathematical development of the subject may be effective in formulating and analyzing, in clear and quantitative terms, theories such as Dirac's et al. concerning the interaction of light with matter in a way that preserves the conceptual simplicity of the underlying ideas. The main general idea, in addition to those already mentioned, is that of the *locality* of interaction, an idea somewhat corollary to that of relativistic invariance. Combining ideas from a variety of mathematical fields (including functional integration, operator theory, hyperbolic partial differential equations, and generalized function theory), a coherent theory arises in which the fundamental equations at last attain definite and natural mathematical meaning. Of course, the questions of existence, non-existence, or uniqueness of solutions are still unresolved. But experience shows that when a solid, general, and conceptually simple mathematical base exists from which to operate, technical progress is likely. The current rate of progress, if continued, might well enable the determination within a few years of the existence or non-existence, etc., of solutions to equations like the contemporary mathematically unexceptionable formulations of the old intuitive equations of quantum electrodynamics—i.e., the Dirac-Heisenberg-Pauli equations for the interaction of light and electrons. (Figure 2).

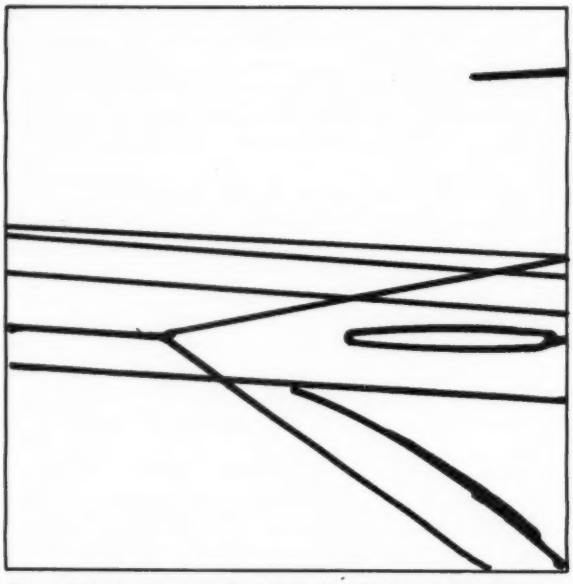


Figure 2. What Comes In Doesn't Go Out! In this schematic section of a bubble chamber photograph, more particles are emerging from the right than are entering from the left. Those emergent are in part "mesons", which are qualitatively quite different from the "protons" which are entering. In addition, the same entering particles do not always produce the same outgoing ones; only the probability of a particular outcome is determined. Such creation and annihilation of particles is predictable from the nonlinearity of the underlying equations. The indeterministic character of the outcome is deducible from the use of non-commuting operator-valued functions in place of ordinary real-valued functions, as in Maxwell's theory.

At the moment, the theoretical situation for the realistic four-dimensional space-time is too technical to describe, except that one must abandon the idea that temporal transitions should describe how the situation at one exact time has developed by a later time, and one must replace the exact times by approximate times. In practice, observation takes place over time intervals which are effectively infinite, and since there is no "exact" time of $\pm \infty$, there may well be no empirically meaningful distinction between the two types of theories. In terms which may be more familiar to some readers, as far as scattering theory is concerned, the use of generalized (distribution) propagators in place of conventional strict propagators is no essential change. But for the finite temporal transitions, which are theoretically of great interest although perhaps not directly observable empirically, a new kind of temporal smoothing is both mathematically natural and apparently effective.

There has been more study of the two-dimensional situation, in which nonlinear scalar equations of the form $\Box \psi = m^2 \psi + p(\psi)$, where p is a given real polynomial, are over the hump of basic understanding, although many open questions remain. The most important lesson learned from this work is that the apparently infinite character of the energy operator, which is central in the theory of the 1920's, is quite substantive. However, it does not matter, partly because of the effectiveness of hyperbolicity ideas, which make it possible to change the interaction sufficiently far out in space without affecting the beginning of the temporal development in the region of interest; and partly because of the applicability of new conceptions of "states" and "observables" in terms of the mathematical theory of so-called C*-algebras. In terms of the Schrodinger states of the 1920's, the temporal development of the system is "infinite" (properly speaking, non-existent); nor can this embarrassment be ameliorated by hyperbolicity ideas. But in terms of states of C*-algebras, the change in state from one time to another is perfectly finite. (Figure 3)

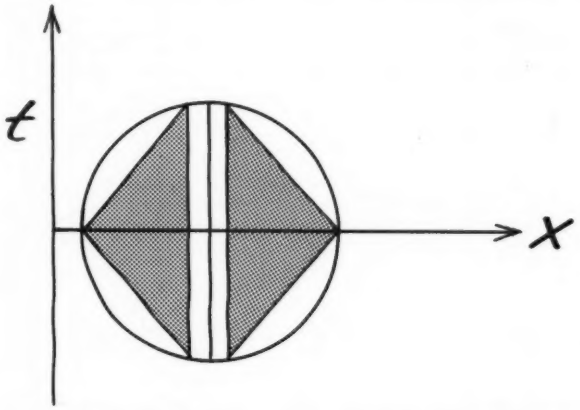


Figure 3. Hyperbolicity vs. Apparent Infinities. Flexible spatial cutoffs for the interaction help to make the theory mathematically sound, without essentially changing it. Hyperbolicity of the equations implies that changing the interaction outside the cylinder will not affect the dynamical propagation of the quantum field within the shaded double cone.

Thus, it now appears unnecessary to change the conventional model for space-time in order to obtain a satisfactory theory of quantized nonlinear partial differential equations. A change in the model for microscopic space may prove desirable for other reasons, such as developments in the theory of particle models. But if this should occur, the basic principles of the mathematical theory of local interactions of quantum fields will probably remain applicable. The key ideas for the elimination of the "divergences"–(1) the use of automorphisms of C*-algebras as a model for dynamical transitions, (2) the absorption of all basic additive (e.g., mass) renormalizations in so-called renormalized (Wick) operations on noninteracting fields at fixed times, (3) the absorption of all basic multiplicative (e.g. charge) renormalizations in the use of distribution propagators, (4) the exploitation of causality features of the free propagation which correspond in conventional theory to the hyperbolicity of the underlying equations–are independent of the character of the space involved. So also is the mathematical character of the particle-wave duality. Hence, the mathematical theory of local nonlinear quantum fields is probably here to stay for a significant length of time.

Contact: Lt Col Paul J. Daily
Telephone Extension 45261

absolute and convective plasma instabilities

DR. A. GARSCADDEN AND DR. P. BLETZINGER
Plasma Physics Research Laboratory, ARL

Generally, in a plasma, the phase velocity, the velocity of advance of a wave train of finite length or of any arbitrary disturbance, and the velocity of energy transmission are all different. This occurs because the medium is dispersive, i.e., the phase velocity is a function of wavelength. The equivalent relation between frequency and wave number $D(\omega,\kappa) = 0$ is termed the dispersion relation.

A plasma exhibits dispersion in two ways. It is dispersive to the propagation of electromagnetic radiation; study of the effects allows the determination of plasma properties. Also, the great variety of instabilities and oscillations of the plasma itself are subject to dispersion. These oscillations range from the high frequency longitudinal electron plasma waves to the low frequency ionization waves.

The distinction between absolute and convective instabilities is also obtained from the dispersion relation. An absolute instability is said to exist in the medium if the disturbance spreads to all finite regions and the amplitude at each point increases indefinitely with time (or, in practice, to some saturation value). A convective instability is said to exist if, at any point outside the originally disturbed region, the amplitude of the disturbance later reaches a value larger than its original amplitude, but diminishes to zero as time increases to infinity. The identification of dispersion relations is a necessary step to the understanding and control of plasma instabilities. Only in a few cases have detailed experimental comparisons been possible.

At ARL's Plasma Physics Research Laboratory, we have been studying the properties of ionization waves in low pressure plasmas. These ionization waves cause large signal modulation in the electron density, in the electron temperature, and in the light intensity emitted from the plasma. For typical plasma diameters of a few centimeters and gas pressures around 1 torr, the waves occur at kHz frequencies with wavelengths of a few centimeters. These features allow accurate systematic studies by experimental techniques which often are not applicable to other instabilities.

We have recently completed a series of experiments on the dispersion and stability of ionization waves in argon, neon, and mercury-argon plasmas. At low pressures, from 0.5 to about 20 torr, spontaneous ionization waves occur at moderate discharge currents. These waves are termed backward-waves (BW), because, although the ionization wave moves in the anode-to-cathode direction, pulsed discharge studies and dispersion measurements reveal that the disturbance creating the wave moves in the cathode-to-anode direction.

Experiments in argon and neon showed that, as the pressure and current increase, a partial contraction of the plasma occurs until, at a certain critical pressure or current, the discharge changes abruptly into a well-defined constricted form with ionization waves often present. The onset of the constriction proceeds as a BW from the cathode at lower pressure, but at higher pressure changes to a forward wave (FW), i.e., group and phase velocities are in the same direction, anode-to-cathode.

A time-space display method, figure 1A, shows the disturbance excited in an argon discharge at 9.2 torr. In the high current (62ma) region, a BW absolute instability is excited; in the low current (20ma) region, a convective BW exists. At intermediate pressures (23 torr in argon) figure 1B shows the discharge conditions obtained were such that constriction and ionization waves (as absolute instabilities) developed simultaneously from both electrodes. At about 35 torr and above, the discharge constricts only from the anode.

In neon the results were similar, except that a higher pressure or current was required for the transition. Since the transition to constriction changes from a BW to an FW, it was reasoned that at a certain condition the wave would

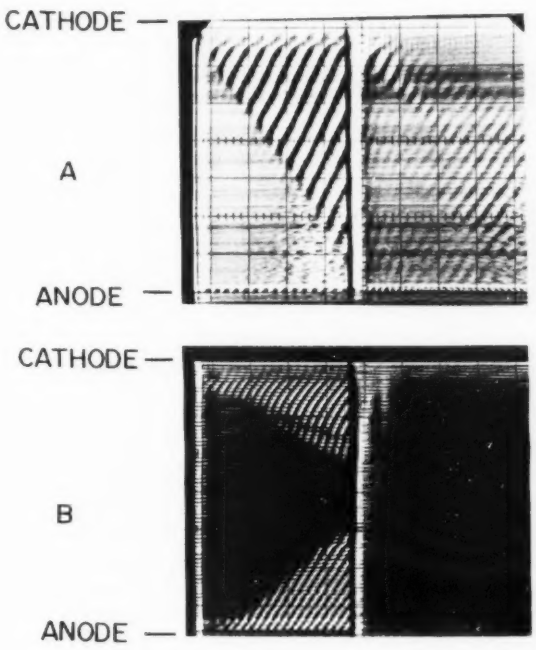


Figure 1. Space-time display of ionization waves in argon; time-base 2 msecs/div. (A) 9.2 torr. (B) 23 torr.

have zero group velocity. A recording was obtained in neon at 65 torr (figure 2) where, in the low current period, the group velocity of the excited wave was approximately zero. The disturbance oscillated in time but did not propagate. Changing the discharge conditions slightly caused the disturbance to become a BW or an FW. This is one of the few observations of plasma waves exhibiting zero group velocity.

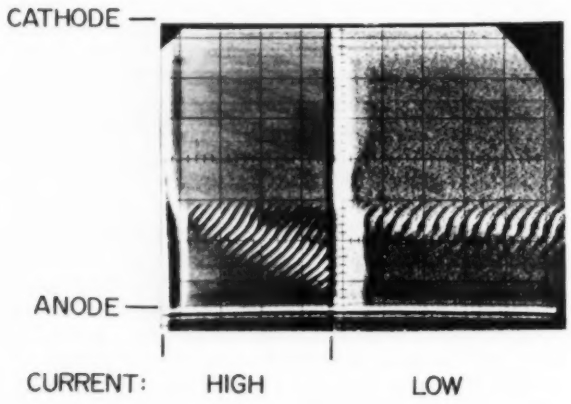


Figure 2. Space-time display of ionization waves in neon; time-base 2 msecs/div. 65.5 torr.

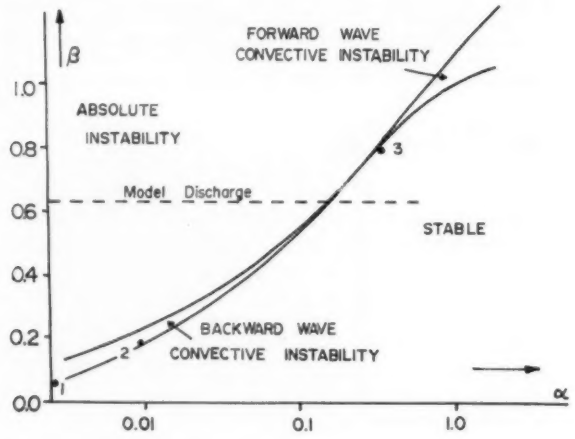


Figure 3. Stable and unstable ionization wave regions as a function of the two discharge parameters α and β.

Analysis of the stability of the ionization waves from the dispersion relations has been made in collaboration with Dr. Simonen of the Princeton Plasma Physics Laboratory. The results are summarized in figure 3. The stability areas are shown in the parameter space α-β where α and β are determined from the properties of the gas and the gas discharge. It was found that α is approximately proportional to P^2R^2, in which P is the gas pressure and R is the tube radius. The points marked are those of different experiments. For an ideal glow discharge $\beta \simeq 0.63$, so that only BWs would be excited. It was experimentally observed that FWs appear only in association with some constriction. Also, as indicated in figure 3, it is easier to obtain a BW convective region at lower α. At $\alpha = 0.25$, it is possible to make the transition from stable to unstable without a convective region. Therefore, the abrupt constriction or occurrence of ionization waves throughout the column can be produced by a discontinuous change in β (e.g., by current modulation) or at this value of $\alpha = 0.25$. It is noted that the FW convective instability area is limited; therefore, the experimentally observed FW striations will often be absolutely unstable.

Similar experiments to determine the dispersion and stability of ionization waves in molecular gas discharges are now in progress. We find that the ionization waves in molecular gases are cathode-to-anode FWs. Because the molecular gas mixtures are found to be irregularly unstable, correlation methods are being used to determine the wave dispersion.

Thus, an apparently straightforward experimental low pressure plasma has proved intriguing and extremely useful, allowing the study of complex wave phenomena which occur in fusion plasma devices, or ionospheric plasmas, and in gas lasers.

Contact: Dr. A. Garscadden
Telephone Extension 54814
Dr. P. Bletzinger
Telephone Extension 53835

REFERENCE

Garscadden, A., P. Bletzinger and T. C. Simonen, "Dispersion and Stability of Moving Striations," *Physics of Fluids*, Vol. 12, No. 9 (September 1969), 1833-1844.

a look at "ROBIN" (ROcket Balloon INstrument) after ten years of Development

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

In November, shortly before the launch of the 300-foot Saturn 5 rocket that took Apollo 12 to the moon, a minirocket measuring only about 6.5 inches in diameter and 14 feet in length was fired from Cape Kennedy. The minirocket, its payload, and its mission were similar to many rockets that have been fired in recent years to support Apollo and other launches from both the Eastern and Western Test Ranges.

The 2-inch diameter Dart, the second section of the minirocket, coasted to an altitude of more than 130 km where it ejected a clear plastic balloon which was inflated to a diameter of about 3 feet by the vaporization of isopentane. Radars then tracked the descent of the balloon to about 30 km to provide a profile of the atmospheric densities and winds in the region to be traversed later by Saturn 5.

The ejected balloon has been given the name, ROBIN, an acronym for ROcket Balloon INstrument. Although ROBIN has become an integral part of the prelaunch preparations at test ranges, its contributions are overshadowed by the more spectacular launches that follow it. The development of the ROBIN dates back to the late 1950's; practically all the development work has taken place at AFCRL.

In a recent paper, "A Summary of AFCRL Passive Sphere Development Efforts and Experience," John B. Wright of AFCRL both reviews the evolution of passive falling spheres for measuring upper atmosphere densities, and presents a set of recommendations for further improvements in the technique.

The passive falling balloon technique is the best currently available for measuring atmospheric densities above about 30 km, the upper limit for conventional meteorological balloon-borne radiosondes.

While the technique is simple (a balloon is ejected from a rocket and its descent is tracked from a ground station), the method for calculating density based on these measurements is not. Density is considered in terms of temperature and pressure. A precise knowledge of the drag coefficient of a sphere over a wide range of flow conditions is required. For this reason, some of the research on the ROBIN has taken place in wind tunnels. Such tests provide one of the essential parameters for computer analysis of the ROBIN free-fall data. Computer computations are in fact the most expensive and demanding aspect of the ROBIN technique. Calculations involve terms for drag force, mass, acceleration, velocity, cross sectional area, altitude, Mach and Reynolds numbers, wind components, gravity acceleration at the earth surface, and others. The calculations are of such complexity that not until 1965 was an acceptable (but still unperfected) computer program formulated, a program that AFCRL still calls the "March 1965" program.

Systems hardware development has the goals of reducing the cost of the system, and extending measurements to higher altitudes. Several rockets have been used with the ROBIN as a payload—the Arcas and Loki-Dart in the 30-60 km altitude region, and the Sidewinder-Arcas, Sparrow-Arcas, and Viper-Dart to attain higher altitudes. During the past five years, the cost of these launches has been cut in half, from about $5000 to $2500.

John B. Wright of AFCRL holds the 2-inch diameter "Dart," the second section of the minirocket which carries the ROBIN balloon. The uninflated ROBIN balloon is shown on the desk.

The balloon design itself has not seen too many changes over the years. Earlier designs all had interior corner reflectors for easier radar tracking, but present radars do not require interior reflectors. Corner reflectors are still used, however, when especially sharp radar returns are needed.

One still unsolved problem in balloon design is the occasional collapse of a balloon after its descent to an altitude of about 40 km. This problem is one of 33

conclusions and recommendations discussed in the Wright report for improving a system that, even at its present state of development, provides the best data available on upper atmosphere densities.

Contact: John B. Wright
Telephone Extension 3283

John B. Wright is a Research Aerospace Engineer in the Vertical Sounding Techniques Branch of AFCRL's Aerospace Instrumentation Laboratory. He has been with AFCRL since 1960 engaged in work on high-altitude meteorological equipment including rocket vehicles, balloons, and parachutes. Part of the work has been the development of the ROBIN falling sphere for measurement of atmospheric density and winds, including hardware and data computational techniques. The rocket work has been concerned with the modification of conventional meteorological rockets for use at higher altitudes, and the launching of several hundred rockets from various U.S. missile ranges.

Mr. Wright received his Bachelor of Science in Mechanical Engineering Aeronautics from the Worcester Polytechnic Institute in 1942. Later that year, he joined the National Advisory Committee for Aeronautics, where he specialized until 1948 in the aerodynamics of high speed compressible flow. From 1948 to 1950, Mr. Wright worked on the aerodynamic design of the XB-52 aircraft for the Boeing Airplane Co. in Seattle, Washington.

Mr. Wright is an Associate Fellow of the American Institute of Aeronautics and Astronautics. He has a number of published scientific reports to his credit.

REFERENCES

(1) Wright, J. B. and Leviton, "The ROBIN Falling Sphere," *COSPAR Rocket Technique Manual*, 1967.

(2) *Stratospheric Circulations*, L. Webb, Ed., Academic Press, 1969, Chapter on "The ROBIN Falling Sphere."

hypersonic turbulent boundary layers

DR. ANTHONY W. FIORE
Hypersonic Research Laboratory, ARL

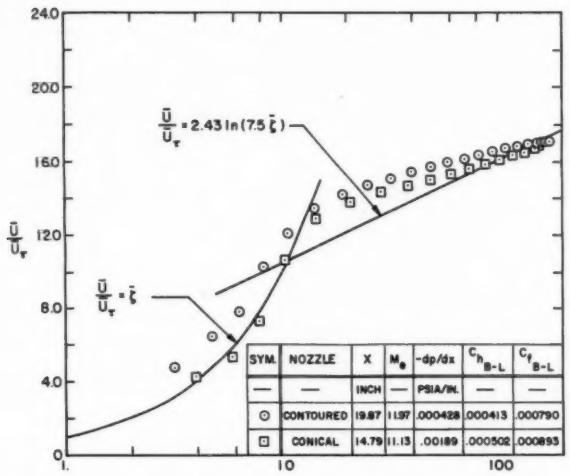
Recently, an experimental research program was carried out on turbulent boundary layers at hypersonic Mach numbers. The program was conducted on the wall of two nozzles in the 4-inch hypersonic wind tunnel of the Aerospace Research Laboratories.

One nozzle was contoured and designed for an outlet Mach 12; the second nozzle was conical and designed for an outlet Mach 11.2 approximately. In both cases the total pressure and temperature through the boundary layer were measured.

Tests were conducted in the wall to a stagnation temperature ratio range of $0.25 \leqq T_w/T_o \leqq 0.35$ and a momentum thickness Reynolds number range of $650 \leqq R_{e\theta} \leqq 1330$. All other boundary layer profiles and surface properties were calculated, using the Baronti-Libby transformation (1). The data were compared with the law of the wall in the incompressible plane, Crocco's theory, the Spalding-Chi technique (2), and other available data.

The velocity profiles at the outlet plane of both nozzles are shown in figure 1. The wall temperature was approximately 651 °R and the momentum thickness Reynolds number was 966. These tests were conducted in the presence of both heat transfer and a favorable pressure gradient. The data are plotted as the normalized velocity ratio $\overline{U}/\overline{U}_\tau$ versus $\overline{\zeta}$ where $\overline{U}_\tau$ is the friction velocity and $\overline{\zeta}$ is the local Reynolds number within the boundary layer. These data are compared with the law of the wall which makes use of the Clauser constants (3, 4). The data in the laminar sublayer region agree reasonably well with theory. In the "linear" portion of the boundary layer, the data have an overshoot where the local velocity through the boundary layer is greater than that predicted by the law of the wall. In addition, the third boundary layer region, commonly referred to as the velocity defect region, does not exist at these Mach numbers.

A phenomenon. which is typical of data obtained on the wall of hypersonic nozzles, can be observed in figure 2. Here, the total enthalpy ration $H - H_w/H_e - H_w$ through the



SYM.	NOZZLE	X	M_e	-dp/dx	$C_{h_{B-L}}$	$C_{f_{B-L}}$
—	—	INCH	—	PSIA/IN.	—	—
⊙	CONTOURED	19.87	11.97	.000428	.000413	.000790
⊡	CONICAL	14.79	11.13	.00189	.000502	.000893

Figure 1. Velocity profiles at nozzle outlet for Re_θ = 966. and T_W = 651°R.

boundary layer is plotted versus the velocity ratio $\overline{U}/\overline{U}_e$. Obviously the data do not agree with the Crocco theory, as they did in the case where similar data were obtained by Young (10) over a flat plate at lower hypersonic speeds. It is believed that this difference between theory and experimental data is caused by the upstream history of the pressure gradient found in hypersonic facilities (5). In addition, figure 2 indicates that two regions are present within the boundary layer. At the outer edge of the boundary layer, the data agree with the quadratic relationship between $H - H_W/H_e - H_W$ and $\overline{U}/\overline{U}_e$, while near the wall, the linear form seems more appropriate. This trend agrees with Alber's and Coates' theoretical analysis (5) for the incompressible turbulent boundary layer in the presence of heat transfer. The linear region near the wall has been found to be the laminar sublayer.

The incompressible skin friction coefficient, which has been obtained by mathematical iteration in the Baronti-Libby transformation, is presented in figure 3. Coles law of corresponding stations (6) is then used to obtain the compressible or actual skin friction coefficient. First, let us analyze the incompressible skin friction coefficient which is plotted versus the multiple of that coefficient and the momentum thickness Reynolds number in the incompressible plane. Included are data of other investigators, as well as an empirical curve obtained by Coles (6) and a curve computed by the Spalding-Chi method (2). A complete analysis is not necessary, as the data speak for themselves. It is necessary to recall that Coles states that the boundary layer over a body will be laminar only when $\overline{C}_f \cdot \overline{R}_{e\bar{\theta}} \geqq 2.0$. This statement was based on data available at the time his report was written. In the light of present data, this statement must be reevaluated; ARL data indicate that a turbulent boundary layer is present at values of $\overline{C}_f \cdot \overline{R}_{e\bar{\theta}}$ as low as 0.73. Observe that these data agree well with the Spalding-Chi theory, but fall below the empirical curve of Coles.

The actual skin friction coefficient data are shown in

SYM.	NOZZLE	X	M_e	-dp/dx	$C_{h_{B-L}}$	$C_{f_{B-L}}$
—	—	INCH	—	PSIA/IN.	—	—
⊙	CONTOURED	19.87	11.97	.000428	.000413	.000790
⊡	CONICAL	14.79	11.13	.00189	.000502	.000893

⊗ YOUNG'S DATA AT M_e=4.91 FOR A SMOOTH FLAT PLATE

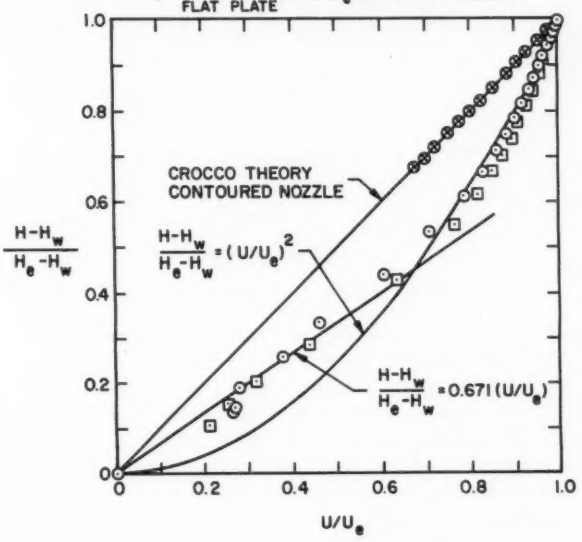


Figure 2. $H\text{-}H_W/H_e\text{-}H_W$ versus U/U_e at nozzle outlet for Re_θ = 966. and T_W = 651°R.

SYM.	REF.	AUTHOR	M	$Re_\theta \times 10^{-3}$	T_w/T_e
●⊗●	1&12	COLES	1.96-4.55	2.2-10.2	1.6-4.74
■	2	MATTING ET. AL.	2.95-4.2	6.2-37.6	2.5-4.1
◆	3	STALMACH	1.74-3.68	2.7-12.4	1.5-3.4
▲	4	SCHUTTS ET. AL.	2.50	6.1-18.8	~2.14
◢	6	NOTHWANG	3.03	13.47	2.64
●	7	KISTLER	3.6-4.7	28.8	4.92
◆	8	LOBB ET. AL.	5-6.8	6.5-8.6	3.3-6.3
◆	9	WINKLER & CHA	5.24	1.0-4.3	3.9-5.6
●	10	HILL	10.00	2.3	8.3
◢	14	LIU ET. AL.	½ ft/sec	0.7-5.4	—
⊙	—	ARL	11.91	0.09-.23	~8.63
⊡	—	ARL	10.83	0.60-1.3	~8.63

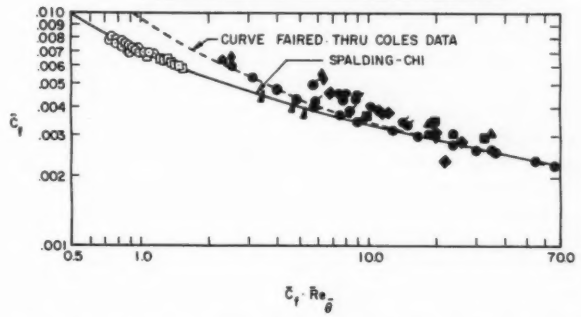


Figure 3. $\bar{C}_f$ versus $\bar{C}_f \cdot \bar{R}e_{\bar{\theta}}$ compared with available data and Spalding-Chi.

figure 4. The data are presented as the product $C_f \cdot F_c$ versus $F_{R\theta} \cdot R_{e\theta}$ and are compared with the Spalding-Chi universal curve. The data appear to have the same trend as the theory, i.e., the product $C_f \cdot F_c$ decreases monotonically with an increase in the product $F_{R\theta} \cdot R_{e\theta}$;

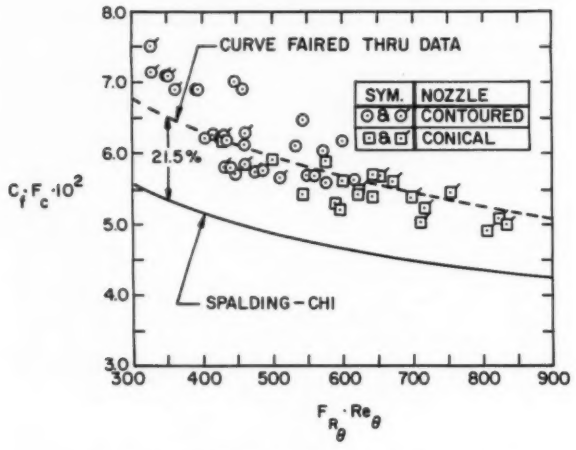


Figure 4. $C_f \cdot F_c \cdot 10^2$ versus $F_{R_\theta} \cdot Re_\theta$ as obtained from the Baronti-Libby transformation compared with Spalding-Chi.

however, these data are consistently about 21.5% higher than the Spalding-Chi universal curve. This difference can be attributed to the wall temperature effect, as proposed by Bertram et al (7).

The Bertram curve and the present data, both given in figure 5, show that the wall-to-stagnation temperature ratios of approximately 0.8 or higher (for both the Baronti-Libby and the Spalding-Chi methods) give results equivalent to the measured skin friction coefficient. As this temperature ratio is decreased from 0.8 to 0.1, the skin friction coefficients calculated by the Spalding-Chi method agree with the measured values; however, those resulting from the Baronti-Libby transformation are much higher than either the measured values or those calculated by the Spalding-Chi theory. The data obtained in the present investigation are in the temperature ratio range of $0.25 \leqq T_w/T_o \leqq 0.35$ and agree very well with the wall temperature effect first encountered by Bertram and his colleagues.

Finally, some interesting facts about the boundary layer and its laminar sublayer are shown in figure 6. In general, both the boundary layer and the sublayer thickness for the contoured nozzle increase with increasing distance from the throat and decreasing Reynolds number. In addition, the boundary layer thickness agrees with Burke's semiempirical equation (8). The first important feature is that the laminar sublayer is very thick, about 20% to 30% as thick as the boundary layer itself; the second important feature is that the sublayer can contain a mixed subsonic-supersonic flow field. At $Re_x = 9.924 \times 10^5$ the sublayer is completely subsonic; however, as the Reynolds number is decreased to 7.591×10^5, it is about 60% subsonic and about 40% supersonic; at the lowest test Reynolds number of 5.284×10^5, the sublayer is approximately half subsonic and half supersonic. This information forces us to change our concepts of allowable surface roughness heights. In a subsonic turbulent boundary layer, it has been accepted that the surface roughness height should not exceed the

SYM.	M_e	$R_\theta \times 10^{-3}$	SOURCE
◆	6.0	19 TO 49	BERTRAM & NEAL
▲	6.8	13 TO 30	BERTRAM & NEAL
◣	6.0	12.9	SAMUELS ET. AL.
●	7.5	2.0	MADDALON ET. AL. *
▼	15.6	2.6	HENDERSON ET. AL. *
♦	20.2	5.2	BERTRAM & NEAL *
▲	7.7	3.5 TO 5.8	WALLACE
▼	18.4	1.25	HARVEY & CLARK +
◥	7.9	11 TO 24	FELLEY
⬢	4.91	5.78 TO 9.79	YOUNG
⊙	11.83	3.4 TO 6.5	ARL - CONTOURED
⊡	10.73	4.0 TO 6.5	ARL - CONICAL

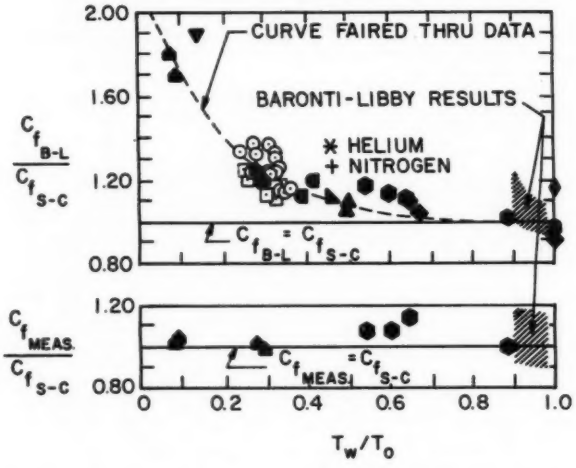


Figure 5. $C_{f_{B-L}}/C_{f_{S-C}}$ and $C_{f_{MEAS}}/C_{f_{S-C}}$ versus T_w/T_o for both contoured and conical nozzle compared with other data.

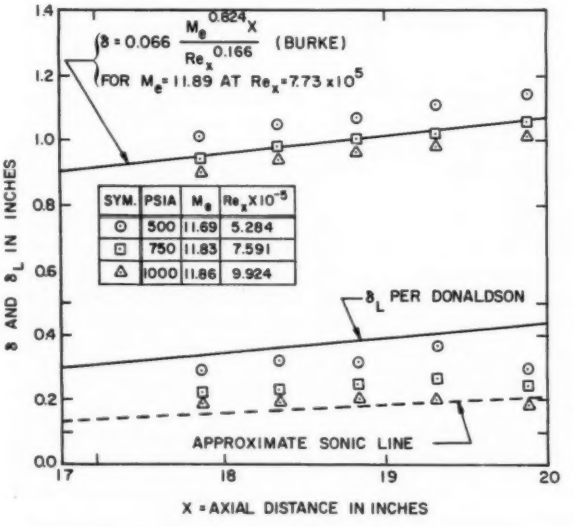

$\delta = 0.066 \frac{M_e^{0.824} X}{Re_x^{0.166}}$ (BURKE)
FOR $M_e = 11.89$ AT $Re_x = 7.73 \times 10^5$
SYM. PSIA M_e $Re_x \times 10^{-5}$
500 11.69 5.284
750 11.83 7.591
1000 11.86 9.924
δ_L PER DONALDSON
APPROXIMATE SONIC LINE
δ AND δ_L IN INCHES
X = AXIAL DISTANCE IN INCHES

Figure 6. Boundary layer and sublayer thickness versus axial distance for the contoured nozzle.

laminar sublayer thickness. For a hypersonic turbulent boundary layer, this definition for surface roughness height no longer holds true, particularly if the Reynolds number is small enough to make the sublayer partially supersonic. Under these circumstances, the surface roughness height should not exceed the height of the sonic line if shock waves, which would have their genesis in the supersonic portion of the laminar sublayer, are to be avoided.

Knowledge of turbulent boundary layers at hypersonic speeds is now meager; however, indications are that as the Mach number is increased to hypersonic values, the laminar sublayer becomes very thick, with the turbulence concentrated in a narrow region at the outer edge of the boundary layer. Under these conditions, the surface heat transfer and skin friction are very near the incompressible laminar boundary layer values. It appears that, although a turbulent boundary layer is present at hypersonic Mach numbers, the surface parameters are "laminar-like" and it may be possible to use these laminar values for engineering approximations. Similar results have been noticed by Kemp and Sreekanth (9) in their research on turbulent boundary layers at Mach 27 to 47 in helium as a test medium. Further research is needed to either confirm or disprove this postulate. Its confirmation would be an extraordinary advantage to the designer of hypersonic manned reentry vehicles and recoverable boosters.

Contact: Dr. Anthony W. Fiore
Telephone Extension 52455

REFERENCES

(1) Baronti, Paolo O. and Paul A. Libby, "Velocity Profiles in Turbulent Compressible Boundary Layers," *AIAA Journal*, Vol. 4, No. 2 (Feb 1966), 193-202.
(2) Spalding, D. B. and S. W. Chi, "The Drag of a Compressible Turbulent Boundary Layer on a Smooth Flat Plate With and Without Heat Transfer," *Journal of Fluid Mechanics*, (January 1964), 117-143.
(3) Clauser, F. H., "Turbulent Boundary Layers in Adverse Pressure Gradients," *J. Aero. Sci.* 21 (1954), 91-108.
(4) Clauser, F. H., "The Turbulent Boundary Layer," *Advance in Applied Mechanics*, Vol. IV, New York: Academic Press Inc., 1956.
(5) Alber, I. E. and D. E. Coates, "Analytical Investigations of Equilibrium and Nonequilibrium Compressible Turbulent Boundary Layers," *AIAA Preprint No. 69-689;* AIAA Fluid and Plasma Dynamics Conference, San Francisco, June 16-19, 1969.
(6) Coles, D. E., "The Turbulent Boundary Layer in a Compressible Fluid," *Rand Corp. Report No. R-403-PR*, Sept. 1962.
(7) Bertram, M. H., A. M. Cary and A. H. Whitehead, "Experiments with Hypersonic Turbulent Boundary Layers on Flat Plates and Delta Wings," Presented at May 1968 AGARD Conference in London, England.
(8) Burke, A. F., "Turbulent Boundary Layers on Highly Cooled Surfaces at High Mach Numbers," Presented at Symposium on Aerothermoelasticity, Dayton, Ohio, Oct 30 to Nov 1, 1961; Air Force Aeronautical Systems Div., *TR 61-645*, pp. 704-741.
(9) Kemp, J. H. and A. K. Sreekanth, "Preliminary Results from an Experimental Investigation of Nozzle Wall Boundary Layers at Mach Numbers Ranging from 27 to 47," *AIAA Preprint No. 69-686*, June 16-18, 1969, Conference on Fluid and Plasma Dynamics.
(10) Young, Frank L., "Experimental Investigation of the Effects of Surface Roughness on Compressible Turbulent Boundary Layer Skin Friction and Heat Transfer," PhD Thesis, University of Texas, May 1965.

nonlinear optics and far infrared radiation

DR. FIELDING BROWN
Physics Department, Williams College

The generation of electromagnetic radiation in the very far infrared region lying between microwaves and visible light has long been a problem of interest to scientists and engineers. This region extends from 0.1 to 1.0 millimeter (100 - 1000 microns) wavelength where little is known about the behavior of matter, and almost no information is available concerning the practicability of communications and radar systems or of radio astronomy above the atmosphere. At wavelengths shorter than those of microwaves, the precise fabrication of tubes and circuit components becomes increasingly difficult, placing a lower practical limit somewhere in the submillimeter range. At the same time, power production decreases to about a milliwatt, presently possible at a wavelength of 0.3 millimeter (300 microns). Since the principal device available for this purpose, the carcinotron, costs around $20,000, its use is greatly restricted.

There are several approaches to the far infrared from the visible end of the spectrum. The oldest is to select, by means of a dispersive element such as a diffraction grating, a small wavelength band from the broad emission spectrum of a hot solid. Unfortunately solids do not radiate efficiently in this range, so that monochromatic sources, constructed according to this principle, are relatively weak.

Another approach is to construct gaseous lasers in the region, such as the well-known H_2O laser operating at 118 microns and the HCN laser at 337 microns. Although the radiation emitted by such lasers is strong and is restricted to a narrow band, it cannot be easily tuned from one wavelength to another and therefore can be used only for studies at arbitrary fixed wavelengths.

Finally, there is the approach through nonlinear optics. With the arrangement presently being studied, it will be possible to select many discrete wavelengths within the far infrared band of interest, using the same apparatus. Although continuous tuning will not be immediately possible, the degree and ease of wavelength selection will be greater than that now achievable in this range with other known systems. The object is to generate an optical beat note between two strong visible or near-visible lasers tuned

to slightly different frequencies. This requires a generating medium which is nonlinear at the frequencies of the input lasers. Just as acoustic beats are produced by the nonlinear response of the human ear, or as radio difference frequencies are generated in a nonlinear crystal rectifier, so optical beats, i.e., difference frequency signals, may be produced in substances which respond nonlinearly to light. A key problem is to find a material with a large nonlinear response. To date, the only nonlinear materials to be tried (for instance in the work of Yajima (1) in Japan, and Pate (2) at Bell Telephone Laboratories) have depended on the nonlinear response of *bound* electrons in crystals. In the first case, a ruby laser was used to produce about a milliwatt of power at 340 microns in a zinc telluride crystal. In the second case, a semiconductor, indium antimonide, was used to generate microwatts of power at 100 microns, using two CO_2 lasers separately tuned in the wavelength range 9-10 microns. A selection of far infrared signals around 100 microns could thus be generated.

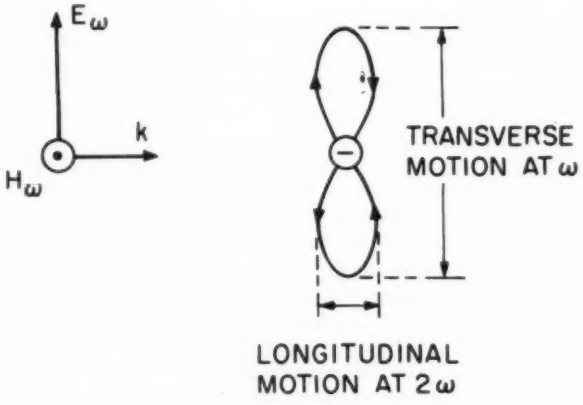


Figure 1. Interaction of an electromagnetic field with a free electron. The existence of small longitudinal component motion at 2ω implies a nonlinear response allowing free electrons to generate difference frequency signals in the far infrared.

Studies are being conducted on the recently discovered nonlinear response of conduction band electrons in solids (3). The object has been to see whether a strong, tuneable, far infrared source can be constructed, based on nonlinear properties. The nature of the nonlinearity can be understood from figure 1. When a free electron, which is taken to represent the conduction band electrons of a solid, is acted upon by an electromagnetic wave, it not only moves up and down along the E-field, but it also executes a small longitudinal motion because of the H-field of the wave (4). The path is actually shaped like a narrow figure eight, with the longitudinal part of the motion occurring at twice the frequency of the impinging wave. Since such harmonic response is a basic property of all nonlinear systems, beat notes can also be generated by the electron if it is excited simultaneously by two incoming waves. Although this so-called Lorentz nonlinearity of electrons has already been well established through studies of second harmonic light, its use to generate difference frequencies in the far infrared has not yet been demonstrated.

As a step in this direction, the Lorentz nonlinearity is being studied in the presence of strong external magnetic fields, supported by an AFOSR grant. The exceptional facilities of the Francis Bitter National Magnet Laboratory at MIT, host to this research, have been of considerable help. As a further step, a theoretical study (5) has been made of the efficiency of difference frequency generation in metal and semiconductors. In n-type indium antimonide, it can be shown that signals at the microwatt level may be produced in the 100-1000 micron range. Thus, it appears that the approach through nonlinear optics may be productive.

The plan therefore is to focus two CO_2 lasers, each discretely tuned to one of the many lines within the rotational bands of CO_2, at 9.6 microns and 10.6 microns, onto samples of n-InSb, and to look for difference frequency signals along the direction of the reflected beam. By selecting lines, the difference frequency may be discretely tuned over a wide range. Both internal and external reflection will be examined, with the theoretical expectation of higher yield for internal reflection.

One immediate application of such an improved source of far infrared radiation is in the field of materials science. Just as intensive studies of the optical, ultraviolet, and microwave spectra of molecules and crystals have led to a deeper and more practical understanding of materials, so will thorough investigations in the far infrared region result in additional important progress. For example, extending dielectric relaxation studies from the microwave range into the infrared will add knowledge of molecular rotations that may improve the understanding of electrical and thermal properties of solids. A better source of radiation would also improve the efficiency of magnetic resonance studies in the infrared, studies that have already contributed greatly to existing knowledge of semiconductors.

In the field of optical communications, there is also interest in far infrared sources. For example, in the heterodyne detection of light, where strong local oscillators are needed, the Lorentz nonlinearity of solids may possibly provide a particularly favorable mechanism. Although direct use of far infrared carrier frequencies for communications within the earth's atmosphere seems unlikely because of the strong absorption of water vapor, these frequencies could be used to advantage in outer space. Communications between satellites and other high flying spacecraft could in this way be carried on without the possibility of jamming or monitoring by ground based systems.

There are potential applications in holography also. Present optical holography systems, because of their high spatial resolution, require great mechanical stability. For instance, if longer wavelengths could be used in the representation of gross objects not needing high resolution, greater stability and simplicity might be achieved.

In view of existing practical interest in improved far infrared technology, it is likely that studies of better ways to generate and detect radiation in this spectral region will be rewarding. It is also likely that the most important

advances will come as a result of the current studies of fundamental processes.

Contact: Capt Roger J. Austin, AFOSR
Telephone Extension 45588

Professor Fielding Brown of Williams College, recently spent 7 months at The Francis Bitter National Magnet Laboratory of M.I.T. to take advantage of its unique capability of producing the intense magnetic fields required by his research in nonlinear magneto-optics.

Professor Brown received the Ph.D. degree in Physics from Princeton University in 1953. Following 7 years as an industrial scientist at the Sprague Electric Company of North Adams, Mass., he joined the faculty of Williams College. He spent his sabbatical year as a Visiting Professor of the Graduate School of Physics, University of Tokyo, working also in the Institute for Solid State Physics with Professor T. Yajima on nonlinear optical problems related to the generation of far infrared radiation. He has also been active in research in cosmic rays, ferromagnetism, and ferroelectricity.

REFERENCES

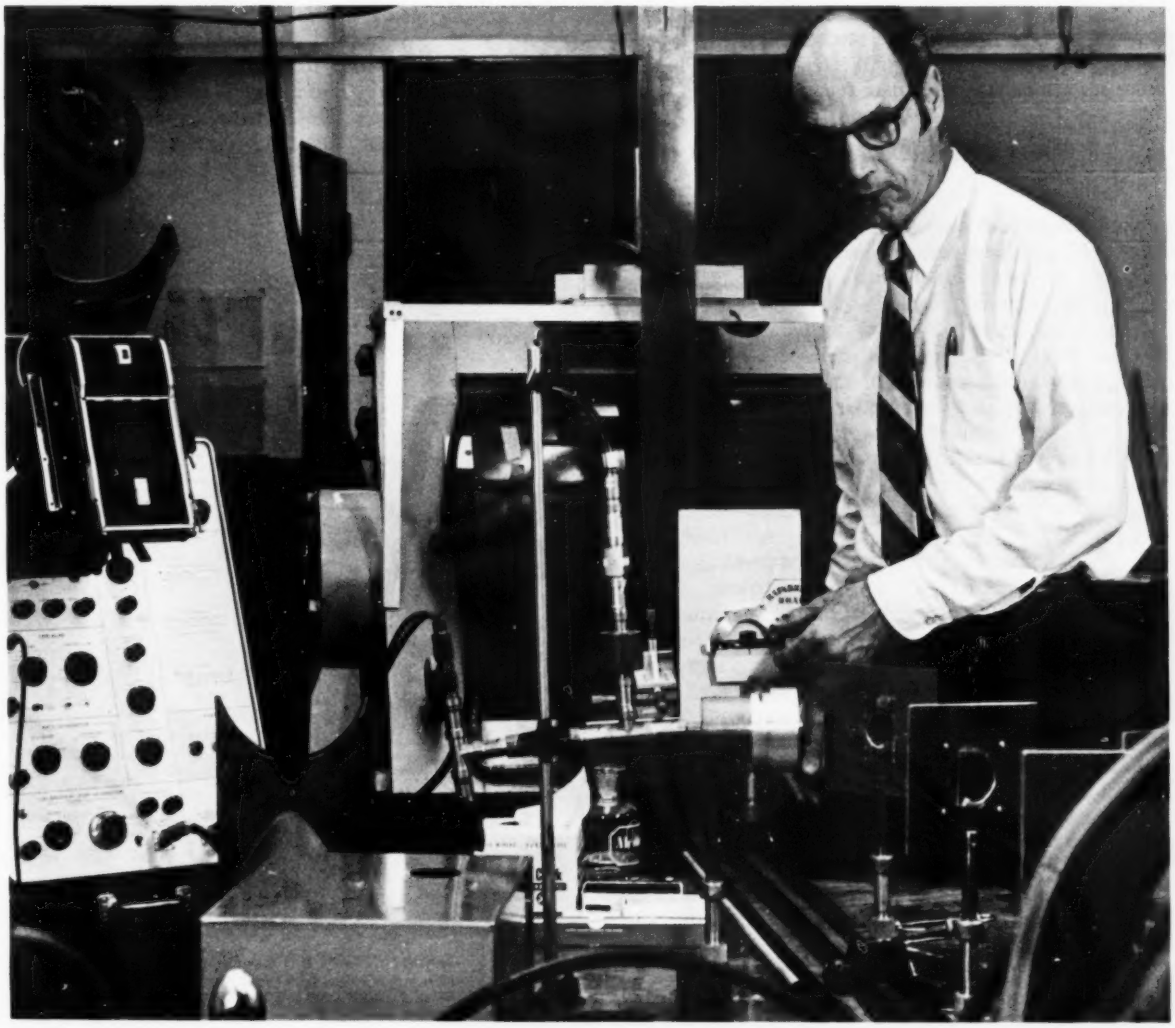
(1) Yajima, T. and K. Inoue, "Submillimeter-Wave Generation by Optical Difference-Frequency Mixing of Ruby R_1 and R_2 Laser Lines," *IEEE J. Quantum Electron*, QE-5 (1969), 140.

(2) Van Tran, N. and C. K. N. Patel, "Free-Carrier Magneto-Optical Effects in Far-Infrared Difference-Frequency Generation in Semiconductors," *Phys. Rev. Letters*, 22 (1969), 463.

(3) Brown, F. and R. E. Parks, "Magnetic-Dipole Contribution to Optical Harmonics in Silver," *Phys. Rev. Letters*, 16 (1966), 507.

(4) Eberly, J. H. and A. Sleeper, "Trajectory and Mass Shift of a Classical Electron in a Radiation Pulse," *Phys. Rev.*, 176 (1968), 1570.

(5) Brown, F., "Proposed Far Infrared Difference Frequency Generation Using Lorentz Nonlinearity of a Solid State Plasma," *J. Quantum Electron* (to be published).



some experimental results of an extremely large area ratio injector system

K. K. JOSHI*
Systems Research Laboratories, Inc., Dayton, Ohio

In recent years, the demands on space power systems have stimulated interest in direct energy conversion processes which do not use moving mechanical parts. Electrofluid dynamic (EFD) energy conversion is one such process in which the fluid dynamic energy is transformed directly into electrical energy by passing a working medium containing unipolar ions or charged aerosols through an electrostatic field.

The basic EFD process is similar to that of a Van de Graaff generator in which the mechanically driven belt is replaced by the flowing fluid. The gas speed in EFD processes can be far higher than the belt speed of a Van de Graaff generator. In addition, parallel staging methods can be more effectively accomplished in EFD generators, even for channels of extremely small sizes. The staging method is most important because the ratio of electrical-power-output to volume varies inversely with a linear dimension of the individual stage. These characteristics of the EFD generator result in power densities in EFD processes many orders of magnitude higher than those resulting from Van de Graaff generators.

However, the pressure ratio of an efficient EFD energy conversion process is so very low that it is incompatible with the pressure ratio requirements for efficient conversion from heat into fluid dynamic energy. One way of overcoming this difficulty is by employing two loops with two working media: one for the thermodynamic process to transform heat into fluid dynamic energy (a high-pressure ratio process), the other for the EFD process to transform fluid dynamic energy into electrical energy (a low-pressure ratio process). Energy transfer from the thermodynamic to the EFD working medium can be accomplished by a fluid dynamic energy exchange process. Analysis has shown that the two working media should have greatly different mass densities and that the flow area of the expanded high-density thermodynamic working medium may be less than 1 percent of the flow area of the EFD working medium.

The present fluid dynamic energy transfer investigation was carried out with only one flow medium (air), but with area ratios of interest for future application; namely, 300

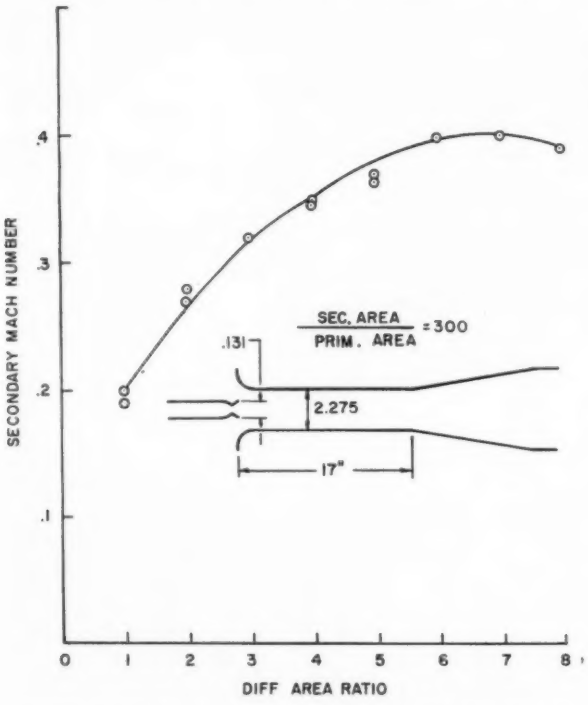


Figure 1. Effect of diffuser area ratio on secondary Mach number at total pressure of 600 PSIA and primary Mach number of 3.

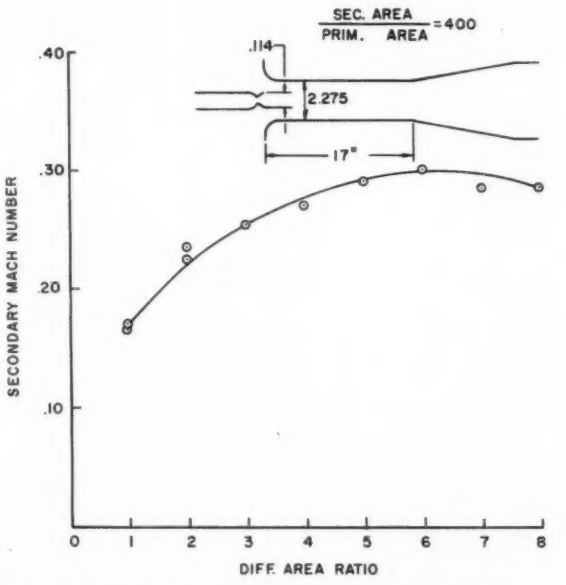


Figure 2. Effect of diffuser area ratio on secondary Mach number at total pressure of 600 PSIA and primary Mach number of 3.

The author wishes to thank M. O. Lawson of the Aerospace Research Laboratories for his helpful comments. This work is supported by the Energetics Laboratory of the Aerospace Research Laboratories, U.S. Air Force Office of Aerospace Research, under contract F33615-67-C-1348.

and 400. Only flow parameter values were necessary for establishing their performance; namely, the volume flow or Mach number of the energized air. This investigation represents only part of one of several research areas for the overall EFD research program at the Aerospace Research Laboratories.

The experimental setup consisted of a Mach 3 nozzle, a concentrically aligned constant area tube in which the primary flow energizes a secondary flow, and many diffusers with different area ratios but with constant diffusion angle. The physical dimensions of this apparatus are given in figures 1 and 2. Achieving the highest secondary Mach number at high area ratios depends on many factors. The three important factors are: complete mixing before entering the diffuser, the rate of diffusion, and the area ratio of the diffuser. In an attempt to assure complete mixing, resulting in a uniform velocity profile ahead of the diffuser, a 17-inch-long constant area tube was used; this tube represented 150 diameters of the Mach 3 nozzle. It was observed by pressure surveys ahead of the diffuser that in all cases the velocity profile was skewed, with the peak velocity occurring somewhat offset of the center line of the mixing tube. In the experiment, a constant diffuser-included-angle of 7 degrees was taken for all diffusers, while diffuser area ratios were varied from 1 to 8. As shown in figures 1 and 2, the optimum diffuser area ratio was found to be 6, a large value not anticipated, particularly in view of the non-uniform velocity at the entrance to the diffuser. Further experiments were conducted with vanes designed to put slight swirl in the flow ahead of the diffuser; however, in all cases the secondary volume flow was reduced.

Contact: Maurice O. Lawson
Energetics Research Laboratory, ARL
Telephone Extension 3355

EXTENDING THE LIFETIME OF RUBY LASERS

Dr. C. Martin Stickley directs the AFCRL program in solid state laser research. In 1960, he designed and fired the first ruby laser to be built by researchers in a Government laboratory.

OPTICAL PHYSICS LABORATORY, AFCRL

After a ruby laser rod has been fired several hundred thousand times (a relatively short operational lifetime), it changes color—usually from pink or red to orange or brown. With this color change comes a loss in laser efficiency. The output energy decreases, and a stronger light pulse is required to energize the laser rod. The efficiency loss is gradual rather than sudden or catastrophic. In Air Force operational range finding systems, long-term sustained efficiency is obviously desirable.

The laser physicist refers to color change in ruby rods as the "formation of color centers." This is a more precise description because the color change is not uniform throughout the rod, but occurs in pockets or along gradients. When color centers form in the rod, energy from the light pump is absorbed and released unevenly.

Many mechanisms have been postulated to explain the formation of color centers. Dr. C. Martin Stickley and his co-workers at AFCRL, in evaluating these possible mechanisms, have shown several to be improbable and have identified others as being consistent with experimental results. Their experiments involved testing scores of laser rods. Obtaining repeatable test results from different rods is seldom possible. Like snowflakes, no two laser rods are exactly the same; even those grown under identical conditions and with identical doping concentrations differ.

Among the possible mechanisms evaluated—and discarded—was the one most widely accepted at present. According to this mechanism, color centers are formed when the original chromium ions, Cr^{3+}, in the aluminum oxide host lattice are transformed to Cr^{2+} or Cr^{4+}. The AFCRL study shows that such transformations do take

place, but they can account for only a fraction of the color change of the laser rod.

The AFCRL study further indicates that color changes result largely from trace impurities in the ruby rod and, most important, from residual impurities on the surface of the rod itself. These impurities remain on the surface even after the rod has been cleaned with great care. The contribution of surface impurities to color center formation was demonstrated most dramatically in tests made with one rod that had been seriously degraded by repeated firings. When a thin outer layer, 0.5 mm thick, was ground off the surface of the rod, the energy output of the rod increased twentyfold. In addition, the rod's threshold energy—a measure of light intensity needed to energize it—also dropped back to its initial value. After grinding, although the rod regained most of the pinkish color typical of a new ruby, a small residual orange coloration remained throughout the bulk of the rod.

Trace impurities in the ruby lattice structure, when subjected to energy from the pumping lamp, are probably dislodged from their original positions, thus creating minute defects in the lattice framework. Annealing experiments showed that this might be the situation. If a degraded ruby rod is heated for 24 hours at 900 degrees C, the color centers can be annealed out and the rod substantially (but not completely) restored to its original efficiency. This would indicate that the impurities, during the high temperature annealing process, are given sufficient mobility to reassume their original sites in the lattice framework.

Mass spectrographic analysis of the samples tested showed that all of them had trace impurities in varying amounts. These impurities are difficult to eliminate even when precautions are taken against contamination during growth and highly purified aluminum oxide and chromium are used.

The most important result of the study, from an applications standpoint, was confirmation that color center formation is induced primarily by the UV and visible-blue radiation from the xenon light pumps used to energize the rods. By filtering the lamp's UV radiation, the efficiency of ruby lasers can be maintained for prolonged periods of operation.

Contact: Dr. C. Martin Stickley
Telephone Extension 2694

Dr. C. Martin Stickley is Chief of the Laser Physics Branch, Optical Physics Laboratory, AFCRL. Dr. Stickley enlisted in the Air Force in 1958 and joined AFCRL in May 1962. Currently, he is conducting studies in laser technology.

Dr. Stickley received a B.S.E.E. (1957) from the University of Cincinnati, an M.S.E.E. (1958) from MIT, and a Ph.D. (1964) from Northeastern University, Boston, Mass.

As an associate member of the DOD/AGED Special Group on Optical Masers, Dr. Stickley has coordinated all AFCRL laser in-house and contract efforts. He is also a member of the Technical Advisory Committee (ARPA/AF Avionics Lab) on gas dynamic lasers and the Advisory Committee (ARPA/IDA) on high power lasers.

Dr. Stickley holds one patent and two invention disclosures on lasers, and is the recipient of several awards for the excellence of 2 papers among the more than 30 he has published or presented at symposiums. He is a member of five professional societies: Sigma Xi, Eta Kappa Nu, Tau Beta Pi, Phi Kappa Phi, and I.E.E.E.

transmitting voice signals more efficiently

DATA SCIENCES LABORATORY, AFCRL

Vocoders have been quietly adopted by military and other Government agencies in recent years for high security voice communications. Because vocoders are commercially available, one would guess that they are also in limited private use by telephone subscribers wishing to guard their telephone conversations.

In any event, vocoders will surely see widespread military and commercial use in the coming years, but for reasons other than security. Their big advantage is bandwidth compression. By converting the analog voice signal to more efficient digital form, more voice channels can be accommodated in a given bandwidth—or, for a given transmitter power, a single message can be sent a greater distance.

The best available 2400-bit-per-second channel vocoders can make this analog-to-digital transformation with only minor losses in intelligibility, speaker identity, or the tonal nuances that convey much extra-verbal information. In fact, with far less bandwidth, fidelity approaches telephone quality.

AFCRL has shown that the output from a channel vocoder can be processed through another stage, leading to a further bandwidth reduction by a factor of three to five. In a report soon to be issued, "Advances in Vocoder Technology," Caldwell P. Smith, Chief of AFCRL's Speech Processing Branch, reports on a processing technique he has developed to achieve this goal. The technique is one of speech pattern matching. When a speech waveform matches one of a set of stored reference speech signal spectra, a relatively simple code for that pattern is transmitted. The original pattern can then be reconstructed at the receiver.

As the intelligibility of words reconstructed from these patterns must be judged subjectively, AFCRL, through one of its contractors, arranged for listener tests. As guides for scoring, a set of diagnostic criteria were adopted. Tested were six fundamental components of intelligibility: voicing, nasality, sustention, sibilation, graveness, and compactness.

A large number of rhyming word pairs were formulated as a means for testing how well each component was replicated. Each rhyming pair differed only by the single component being tested. An example of a word pair used to measure sustention is the pair "fin-pin." The initial consonant of "fin" is sustained; that of "pin" is abrupt. Examples of other word pairs in which the first word is representative of the quality being tested are: for voicing, "dot-tot;" for nasality, "mend-bend;" for sibilation, "seem-theme;" for graveness, "weed-reed," and for compactness, "kit-pit." The tests were designed to see how

often a word was confused with its mate. Words were presented singly to the listener, not as parts of sentences.

A reasonable initial assumption was that, as the number of stored reference patterns increases, confusion between words in a pair would decrease. The number of stored patterns, ranging in number from 497 to 3996, were varied through 12 increments. Corresponding data rates over this range are 450 to 600 bits per second.

Contrary to expectations, the listener tests showed that the pattern-matching technique is relatively insensitive to the precise number of stored voice patterns. Overall intelligibility scores (the percent of words identified correctly) ranged from 82.6 percent for 497 voice patterns to 91.9 percent for 3996 patterns. But, within this overall score, some of the six intelligibility components were easily processed to produce words that are immediately clear. Others proved more difficult. Sibilation test pairs—"jest" and "guest," for example—were rarely confused. Taking the mean scores for all the tests, the results were: for sibilation, 97.9 percent; for nasality, 95.1 percent; for compactness, 93.0 percent; for voicing, 88.4 percent; for graveness, 86.7 percent, and for sustention where the listener had to distinguish between such pairs as "vote" and "boat," 67.0 percent.

Smith and his co-workers at AFCRL are highly encouraged by these results and think they can improve the percentages in all six intelligibility categories. They also believe that they can reduce data rates by about 30 percent with a coding scheme that takes into consideration pattern probabilities.

Looking further ahead, the AFCRL group believes that data rates can be lowered still more—to perhaps 200 bits per second—by reducing redundancies in the time domain. The data flow would be compressed during transmission, and expanded again to normal speech rates at the receiver. Last, and perhaps farthest on the horizon, the pattern-matching technique can lead to peripheral equipment for the generation of a voice output from a computer system. Voice output would be a step toward the HAL-type man-machine dialogues which intrigued viewers of the film, "2001, A Space Odyssey."

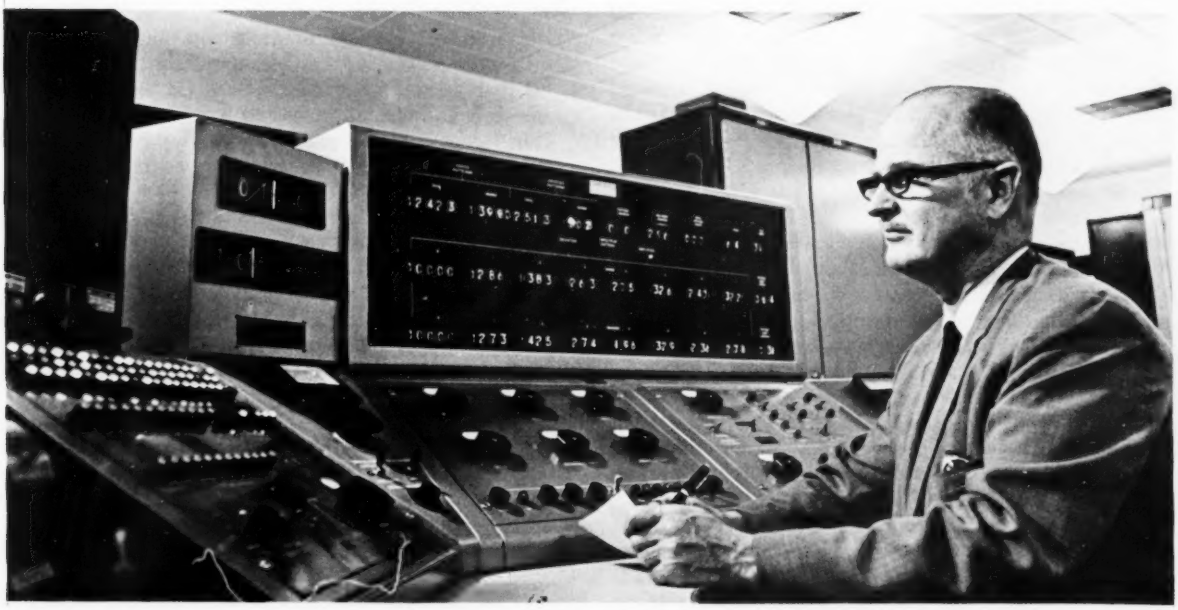
Contact: Caldwell P. Smith
Telephone Extension 3712

Mr. Caldwell P. Smith is a research electronics engineer in the Digital Speech Compression Branch of AFCRL's Data Sciences Laboratory. He has been with AFCRL continuously since 1946, except for a year's leave of absence in 1954 to study under a Fulbright Research Award.

His early experience in radio and radio broadcasting was followed by four years in the Air Corps (1941-1945) as Squadron Communications Officer. His duties with the Air Corps first concerned supervising the installation of VHF radios in Spitfire IX aircraft and later setting up ground communications. After returning from overseas, he attended the Harvard-MIT Electronics and Radar School (1944-1945).

Presently, he is conducting research on methods and techniques for advancing the reliability and efficiency of digital voice communications and the distance over which effective transmission can be established effectively. He has inaugurated a new approach to speech compression and has succeeded in reducing the data-rate requirement of digital vocoders.

Mr. Smith is a member of the Technical Committee on Speech Communication of the Acoustical Society of America and is also a member of the Research Society of America. He is the holder of six U.S. patents relating to speech analysis and processing, and has published more than 20 articles on his work in various scientific journals.



Caldwell P. Smith originated the concept of speech pattern matching which promises to bring greatly improved efficiencies in the transmission of speech signals. Purpose of the work is to reduce the bandwidth needed to transmit speech signals.

the SNAP-SHOOT GUNSIGHT

Directorate of Aerospace-Mechanics Sciences, FJSRL

INTRODUCTION

Over the past several years research associates of the Frank J. Seiler Research Laboratory at the USAF Academy have been investigating the application of modern mathematical optimization techniques to the analysis of aircraft and missile pursuit and evasion problems. In conjunction with this project, Majors S.W. Gilbert, A.E. Preyss, and R.E. Willes of the USAF Academy faculty devised a new concept in fire-control computation for fixed-gun air-superiority-type aircraft called the "snap-shoot gunsight." Their research was encouraged by Hq ADC and supported with OAR funds. They were assisted by 2d Lt J.E. Justin, USAF Academy Class of 1969, who, on temporary assignment to FJSRL in June 1969, completed an analog-computer simulation of aerial combat between two independently controlled aircraft, one equipped with the snap-shoot gunsight.

MOTIVATION FOR RESEARCH

Experience of our pilots in Southeast Asia has shown clearly that, although rockets and guided missiles extend the lethal radius of a fighter aircraft, these weapons are useless during a close-in, maneuvering air battle. The time required to lock-on, prepare, launch, and guide a missile may exceed the duration of the encounter. Even if a launch is possible, appropriate evasive maneuvers by the enemy pilot can defeat the missile guidance systems.

So clear is the evidence that the gun is still the most versatile air-to-air weapon, that most of our first-line fighter aircraft are being fitted with the General Electric Vulcan, M-61. This gun, capable of firing up to 6000 rounds per minute, provides the fast reaction and target area saturation needed for the close-in, maneuvering engagement.

However, the gun is only as accurate as the method used to aim it. Unfortunately, the Lead-Computing Optical Sight in common use today does not satisfy the accuracy required during a maneuvering air battle. Since lead-computing gunsights are based upon weak assumptions of anticipated target motions, they may be defeated if the evader does not conform to these assumptions. Furthermore, an accurate firing solution requires at least one second of *smooth* target tracking. During a close-in maneuvering encounter, such constraints are enough to degrade the system's performance. Only after long training on standard passes, using standard approaches and firing at close range, does a pilot feel confident that he fully understands the gunsight's reactions to various attack conditions. He must learn to compensate for "nonstandard" attack conditions and to make allowances for computational deficiencies.

A pilot who is engaging an optimally-evading target must devote full attention to optimum performance of his own aircraft and therefore, cannot adequately compensate for gunsight inaccuracies. During a brief encounter, there may be only a few momentary firing opportunities. A gunsight should accurately indicate these opportunities. The lead-computing gunsight, due to the tracking time required and the weak lead-angle prediction assumptions, cannot meet these requirements. In fact, lead-computing gunsights often indicate firing opportunities that do not exist. Conversely, they may indicate an aiming error when a hit could actually be scored. In short, the lead-computing optical gunsight is easily defeated by an aggressively-maneuvering target.

The need for an improved gunsight system is evident when one considers the increased speed and maneuverability of modern aircraft. The snap-shoot gunsight concept eliminates the element of probability and the weak assumptions of the lead-computing gunsight. Furthermore, the snap-shoot concept does not require target tracking in any form in order to provide an accurate aiming solution. Thus, evasive target maneuvers do not induce computational errors for which the pilot must compensate.

DESIGN THEORY

The snap-shoot concept attempts to arrive at a more realistic division of responsibility between man and machine. The snap-shoot gunsight relies heavily upon the pilot's natural predictive ability, while giving the computer the task of determining accurate bullet trajectories and displaying them electronically to the pilot.

The inventors contend that the pilot is in a much better position than the computer to determine future target motion. Training in formation flying and air combat normally provide the pilot with experience in predicting a target aircraft's future motions. He can generally anticipate evasive maneuvers in time to take appropriate compensating action to track the target with his own aircraft.

The computer calculates bullet trajectories relative to the firing aircraft, using parameters available to an onboard device such as heading, pitch, and roll angles and rates, as

well as angle of attack and speed of the pursuit aircraft, and ambient air density. The computer continuously calculates the bullet trajectory which would have occurred if the gun had actually been fired.

Gunsight information is presented to the pilot on a heads-up electronic viewing screen. A typical display might include the target's present position, as detected by onboard radar, and the gunsight "pipper," representing that point on the bullet trajectory which is at the range of the target.

A correct solution to the fire-control problem exists whenever the pipper is on-target, regardless of the control used to get it there. The pilot, observing the evader's actions, maneuvers his aircraft as necessary to cause the pipper to cross the target display. When he anticipates the crossing of pipper and target, he snap-shoots—and so, the name of the gunsight.

With the simplified display, the pilot has an exact indication of when a firing opportunity occurred. He must, of course, anticipate the occurrence of these opportunities by observing the pipper motion relative to the target display, and must commence firing soon enough to have a bullet at the indicated point when the pipper and target cross. If he is able to keep the pipper on-target for the time-of-flight of a projectile, while actually firing, the hit probability is significantly increased. Furthermore, if the pilot tracks the target in this manner, he is really solving the lead-angle prediction problem, including the higher-order acceleration effects. However, tracking is not a prerequisite of this system. If the pipper momentarily passes through the target and if the pilot fires soon enough, at least one hit would be scored. In a maneuvering battle, where there may be only one such firing opportunity during the entire engagement, the advantage afforded by the snap-shoot gunsight is obvious. Furthermore, the snap-shoot gunsight incorporates the advantages of tracer rounds without actually delivering them, a decided benefit, since tracers relay information to the evader as well as to the pursuer.

SIMULATION.

Simulations, such as the one described below, indicate that, although the pilot's steering task is somewhat more difficult with the snap-shoot gunsight than with the lead-computing optical sight, the snap-shoot sight does give the pilot accurate and positive indications of firing opportunities.

One of several simulations developed to evaluate the new gunsight concept was an analog-computer simulation of aerial combat between two independently controlled aircraft, one of which was equipped with a snap-shoot gunsight model. This simulation was mechanized on the Applied Dynamics AD/4 hybrid computer at the USAF Academy.

The computer was programmed with flight dynamics for two typical fighter aircraft. Two miniature control sticks, one for the pursued fighter, the other for the pursuer, were provided to induce roll motion by left and right stick deflections, and pitch motion by fore and aft stick deflections. The pursuer's controls also included a trigger button, devised to duplicate the attacker's firing of his gun.

The gunsight computations were also programmed into the computer. The heads-up display was simulated by the computer's oscilloscope screen. Because there was no real target aircraft visible to the pursuer, an inverted T, representing the evading aircraft's wings and vertical stabilizer, was used as the target display. This T figure rotated under the combined roll control of the two control sticks. The gunsight pipper was displayed as a circle with diameter equal to the wing-span of the evading aircraft. A local horizontal, which rotated counter to the pursuer's roll control, was displayed to assist the pursuit pilot.

The simulation was unrealistic in several respects: first, the evader could see the pursuer's display; and second, the pursuer could not see a real evading aircraft (helpful in predicting the evader's motions), although he could observe the evader's actions with the control stick. Nevertheless, a fairly realistic combat engagement between pilots with complete freedom of control was possible with this mechanization.

The gunsight was evaluated by the pursuing pilot's ability to pass the pipper across the target and to predict the target's motion, firing only when hits were possible. Results of this simulation, with a number of experienced pilots at the simulation controls, indicated that it was possible to track with the snap-shoot pipper, and that the snap-shoot gunsight does provide the pursuit pilot with positive indications of firing opportunities against aggressively-maneuvering targets.

RESULTS.

As a result of this research, Aerospace Defense Command has initiated a Required Operational Capability, ROC No. ADC 13-69, 14 July 69, to provide fixed-gun air-defense fighters with the snap-shoot gunsight. Several potential contractors have also followed this development closely. For example, Honeywell, Inc., of Minneapolis, has mechanized this gunsight concept, calling it the "Hot Line" gunsight.

Contact: Major John P. Hyde
Telephone Extension 3120

REFERENCES

(1) Gilbert, S. W., A. E. Preyss and R. E. Willes, "Design Philosophy for Aircraft Gunsights," USAF Academy, Colo., 1969.

(2) "Snap-Shoot Gunsight for Fixed-Gun Fighter Aircraft (U)," *ROC No. ADC 13-69*, HQ ADC, Ent AFB, Colo., 14 July 1969.

(3) Gilbert, S. W., A. E. Preyss and R. E. Willes, "Snap-Shoot Gunsight for Fixed-Gun Fighter Aircraft," *Technical Report #69-3*, USAF Academy, Colo., December 1969.

(4) Gilbert, S. W., J. P. Hyde, J. E. Justin, A. E. Preyss, G. E. Thompson and R. E. Willes, "The Snap-Shoot Gunsight," *Technical Report #SRL 69-0008*, The Frank J. Seiler Research Laboratory (OAR), USAF Academy, Colo. 1970.

variations in solar ultraviolet radiation through a complete solar cycle

AERONOMY LABORATORY, AFCRL

Solar extreme ultraviolet (EUV) and soft x-ray (XUV) radiation fluxes represent the major inputs in shaping the physical characteristics of the earth's upper atmosphere. Since these characteristics are known to affect aerospace activities in general, both descriptive and predictive knowledge of these environmental characteristics are required for the execution and planning of Air Force functions such as those involving surveillance, detection guidance-control, tracking, trajectory-prediction, interception, and communications in the aerospace medium.

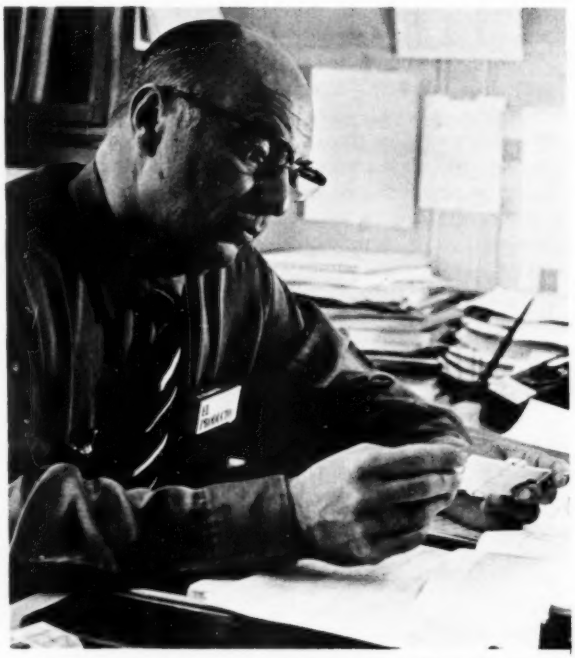
Since 1959 AFCRL has flown scores of Aerobee rockets from the White Sands Missile Range in New Mexico to measure solar emissions of extreme ultraviolet radiation. The rockets have all carried a grazing incidence grating spectrometer, mounted on a biaxial pointing control to keep the spectrometer pointed at the sun throughout the rocket flight. The rockets were usually sent to altitudes above 200 km where little atmospheric absorption of EUV energy occurs.

Data on solar EUV emissions have now been accumulated over a complete solar cycle. Dr. Hans E. Hinteregger, who has directed these investigations, and his co-workers at AFCRL have recently reported on the variations in solar UV emissions over this 11-year period. For the study, they selected data from the 15 rockets that produced the most accurate results over a wavelength range of about 1270 to 230 angstroms.

Solar EUV is generated by ionized gases in the solar atmosphere. Most emissions originate in the solar chromosphere, the region between the visible surface of the sun, the photosphere, and the familiar solar corona. EUV emissions occur at discrete wavelengths which are the characteristic emission lines of particular gas species. In the AFCRL study, nine emission lines were analyzed.

Not surprisingly, the average solar EUV flux (radiation intensity) was seen to be lower during the quiet period of the 11-year solar cycle than during the solar active period. Plots of the flux of emission lines versus the year of occurrence all have the same general shape, showing a depression of average flux during the quiet years. Flux values recorded during the latter part of 1968 (an active period) exceeded minimum 1963-1965 values by a factor of about 1.5 for a majority of the lines. However, especially pronounced variations were noted for a few lines; for the highly ionized species, Fe XV and Fe XVI, the lines showed an increase of a factor of 4 from solar minimum to solar maximum.

The AFCRL study correlated EUV data with 10.7 cm radio emissions from the sun. The Algonquin Radio Observatory in Ottawa continuously monitors such radio emissions; these data are used by many researchers as a convenient indicator of solar activity. Although the correlation is not precise, a rough relationship can be seen. For the data reported, a variation by a factor of 1.5 in the EUV flux corresponds to a variation by a factor of about 2 in 10.7 cm flux. A similar correlation appeared in data from an AFCRL experiment carried aboard NASA satellite OSO-III in which the variation in EUV and 10.7 cm fluxes were recorded over one 27-day revolution of the sun.



Dr. Hans E. Hinteregger is Chief of the Solar Ultraviolet Branch of AFCRL's Aeronomy Laboratory where he is responsible for ultraviolet radiation studies carried on both in the laboratory and by rocket and satellite instrumentation for solar flux measurements in the region below 1300 angstroms.

Dr. Hinteregger received the Diplom Ingenieur in 1944 and the Dr. Technologie in 1947 from the Vienna Institute of Technology, both degrees summa cum laude. After four years of research and teaching, he accepted the invitation of the Air Force to set up the AFCRL effort on extreme ultraviolet photon flux analysis. His study of the absorption of this radiation in the earth's upper atmosphere has received international recognition. In 1960 Dr. Hinteregger received the Guenter Loeser Award for outstanding achievement in research from AFCRL, and the ARDC Science and Engineering Symposium Award; in 1961, the Meritorious Civilian Service Award; and in 1966, the Air Force Exceptional Civilian Service Award. He is a member of five professional societies and the NASA Space Science Steering Committee, and has published more than 50 articles on his work.

Contact: Dr. Hans E. Hinteregger
Telephone Extension 3311

Surface Physics Department of the Cavendish Laboratory University of Cambridge, England

LT COL R. BOVERIE, EOAR

A general survey was made of the research activities of the Surface Physics Research Group, Cavendish Laboratory, University of Cambridge, and of the specific research supported by AFOSR. The Surface Physics Group consists of about 20 visiting senior research scientists and 24 PhD students, specializing in physics, chemistry, metallurgy, and engineering, who use an interdisciplinary approach in conducting research in four general areas: surface properties, strength properties of solids, solid state physics, and decomposition in the solid state.

SURFACE PROPERTIES

Research in surface properties involves the application and the development of physical techniques to study surface topography, surface defects, and surface irregularities that can be determined with high precision to within a few angstroms. Molecularly smooth surfaces, liquid or gaseous media interposed between the surfaces, and adsorbed monomolecular surface films are all used to determine directly the surface energy of solids, both clean and in the presence of adsorbed films. The structure of the surface and of adsorbed layers only one molecule thick is being studied, using specially designed electron diffraction apparatus with an operating range between 20 V and 200 V; penetration is so gentle that only the outermost atomic layers cause diffraction. Study of the diffraction of adsorbed hydrocarbon molecules, fluorocarbons, and other specially "tailored" molecules provides insight into their action as lubricant films.

A concentrated study is being conducted on surface properties, adhesion and friction of polymers, and the changes caused by surface films. Related studies are concerned with the viscoelastic properties of polymeric solids under high pressure and at large strains, and the interaction of rubbing solids in high vacuum at high temperatures (up to 2000°C). High temperature studies have shown that it is possible to form surface films which provide effective lubrication up to 1100°C; but under high vacuum, at pressures of about 10^{-10} torr, the surface films are gradually removed by repeated sliding which influences friction and subsurface deformation. These experiments, now being extended to extremely low temperatures (ca.4°K), will be applicable to the behavior of rubbing surfaces in spacecraft.

Studies in single crystals have shown that the anisotropy of friction is caused mainly by penetration and subsurface deformation of crystals. In brittle crystals, fracture is explained by the resolved shear stresses and mode of crystallographic deformation.

New methods have been developed to prepare microcrystals of uniform and controlled size of a few hundred angstroms for study of their physical and surface properties. Also under study are the influence of surface defects, microcracks, and surface films on the movement of dislocations and on the strength properties of solids.

STRENGTH PROPERTIES OF SOLIDS

New experimental techniques are being used to study the strength properties of solids: specifically, the tensile strength, hardness, creep, and internal and surface friction of refractory metals and nonmetals up to 2500°C. Of particular interest are the deformation and strength properties of the refractory carbides and borides. These materials are very hard at room temperature, but decline abruptly in strength at temperatures well below their melting points. This behavior, which depends on their physical structure and stoichiometric composition, can be studied in detail only in single crystal material. Such crystals are being grown with some success under the required conditions of composition and contamination. Other classes of materials, such as ice and polymeric solids, are also being studied.

A general study of the deformation of solids at high rates of strain includes metallographic studies of metals under hypervelocity impacts reaching 7 km/sec; work on high-speed liquid impact; and investigation of fracture and stress-wave propagation in a wide range of solids. High-speed cameras, recording at framing rates up to 10 million/sec with exposure time as low as 10^{-9} sec, are used to follow the deformation and fracture processes. The highest fracture velocities have been recorded in brittle crystalline solids with well-defined cleavage planes; this appears to be related to a suppression of the branching which occurs either at high crack velocities or when stress waves interact with the crack in isotropic solids. Under consideration is possible application of the controlled fracture of brittle conducting solids to circuit breaking.

A study of the impact of high-speed microparticles on solid surfaces, bridging the gap between hypervelocity impact and radiation damage, deals with microparticles of the order of 10^{-4} cm diameter with surface impact velocities of several hundred meters/sec. The study of high-speed liquid impact is related to the practical problems of the "rain erosion" of aircraft, and to the erosion of turbine blades moving at high velocity through steam. High velocity impact collisions include the possibility of impact between a space vehicle and micrometeorites.

SOLID STATE PHYSICS

The solid state physics studies deal with electron energy levels in the valence band and with exciton lines near the conduction band in various solids. Their levels are estimated from the optical absorption spectra and photoconductivity of thin crystals at liquid helium temperatures. In molybdenum disulphide, a solid which has layer structures, it is possible to cleave crystals one unit cell thick (less than 20 Å). Optical and X-ray measurements on high conductivity semiconductors, and on the nature of transition from semiconductor to a semimetal, also yielded evidence on the "Mott" transition. Recent transition studies include amorphous semiconductors. The breakdown mechanism is not yet fully understood. It is known that crystal defects influence the electrical properties of thin crystals and films, particularly the electrical breakdown of insulators such as mica, ionic solids such as MgO, and semiconductors. Electron microscopy is used to study the defects in thin crystals introduced by the "ion implantation" method at a pressure up to 80 kilobars in order to obtain information on band structure from optical absorption spectra up to 120 kilobars. Measurements are being made in the variations of resistance and lattice parameters, phase changes at high pressures, and the defects in pure and doped crystals of II-VI semiconductors as little as 100 Å thick.

Radiation damage to solids, using fission fragments and fast helium and carbon ions at high energy, and heavy ions of magnesium and zinc at low energy, is being studied by electron microscopy to determine the effect of implanted ions and to obtain information on the nature of particle interaction with a crystalline solid.

DECOMPOSITION IN THE SOLID STATE

Research in solid state decomposition deals with the early slow stages of the process and with its transition to extremely fast reaction and detonation. Crystals of azides are subjected to heat, light, and bombardment with high-velocity ultra-fine particles, and their rates and modes of decomposition are studied by transmission and scanning electron microscopy and high-speed photography. The crystals are of uniform size of a few hundred angstroms with surface-to-volume ratio very large. By using mass ion spectrometry in ultrahigh vacuum, it is possible to study the kinetics of the decomposition of the first monolayers and small crystals. The slow decomposition of azide crystals appears to be predominantly a surface phenomenon.

By determining the electron energy levels in solids, the electronic structure of some solids can be related to their stability, and solids that will decompose readily or explode can be predicted. Studied also was the role of defects less than one micron in diameter on the propagation of low velocity detonation, as well as the formation of microjets in liquid explosives and their part in the initiation and propagation of explosion. New decomposition studies of solids include thermal and photochemical decomposition at high pressure and the decomposition rate of solids in the finely divided state.

AIR FORCE SPONSORED RESEARCH

Research on the growth of burning to detonation in liquids and solids at the University of Cambridge is being supported by the Air Force Office of Scientific Research.

For liquids, investigations are being made of cavitation, cavity collapse, jetting, the importance of initiation and deflagration, and detonation transition.

For solids, studies are being made of the role played by fractures in starting and stopping explosions; fast reactions started by UV and laser light, hot wires, and microparticle impact; hot spot sizes; critical explosion temperatures; and defects in explosives using transmission electron microscopy at low-beam densities, and X-ray microscopy.

The research may ultimately have important application to the design of reliable rocket motors; to the safe manufacture and handling of explosive materials; and to the development of appropriate methods for use in situations where fuel droplets are exposed to shocks, or where fuel droplets may impact surfaces, causing heating and jetting of the droplets.

Contact: Lt Col R. T. Boverie
EOAR
APO New York 09667

statistical prediction of solar flares

SPACE PHYSICS LABORATORY, AFCRL

The larger the sunspot, the more likely it is that the sunspot will produce a solar flare. And if that sunspot produces a flare on one day, it is more likely to produce another flare on the next day. By analyzing past records of sunspot sizes and their tendency to produce flares, it is possible to derive a set of probability tables for predicting the likelihood that a particular sunspot will produce a flare of a given magnitude within the next 24-hour period.

Alfred E. Reilly of AFCRL, together with Isadore Enger and Abraham Pavlowitz (both of the Travelers Research Center, Inc.), have compiled such a set of probability tables by using daily records of sunspots and flares during the period 1957 through 1964. Their study is a part of a joint AFCRL/Air-Weather-Service project whose objective is to forecast changes in the space environment, changes that originate from the sun. Solar flares are of particular interest because they sometimes produce huge bursts of high-energy protons that cause widespread radio blackout in the Arctic regions.

During the 1957-1964 period covered in the study, 13,143 sunspot group observations were analyzed. (A particular sunspot group analyzed on 7 days would constitute 7 observations.) Each sunspot group was placed into 1 of 10 size categories. From the 13,143 cases, the largest flare produced by a sunspot group on a particular day was selected for recording. Flares are ordinarily classified by intensity on a scale of 0 through 4. The AFCRL investigators tabulated flares in only two categories: Class 1 flares and flares of Class 2 or greater. Most flares fall into the Class 1 category, the ratio being about seven Class 1 flares to one for all other classes combined.

Alfred E. Reilly of AFCRL has examined more than 13,000 sunspot groups and solar flares associated with these sunspots. From these studies, he has derived a statistical table on the probability of flares of given magnitudes being emitted by sunspot groups of varying sizes.

For an average size sunspot group covering an area of about 500 millionths of the visible solar hemisphere, the AFCRL statistical tables indicate that if such a sunspot group produces no flare on one day, the probability is 10 percent that it would produce a flare of Class 2 importance or greater on the next day; however, if the sunspot group produces a Class 1 flare on one day, there is a 17 percent probability that it would produce a flare of greater magnitude on the next day. Again, if the sunspot group produces a flare of Class 2 magnitude on one day, there is a 24 percent probability that a flare of equal magnitude would occur on the next day. Thus, the greater the flare produced on one day, the greater is the probability of producing a Class 2 or greater flare on the next day.

For the largest of the 10 AFCRL sunspot group categories—a sunspot group covering more than 1200 millionths of the visible solar hemisphere—these probabilities become 12, 31, and 49 percent, respectively. For the smallest size category—a sunspot group covering less than 30 millionths of the visible hemisphere—the probabilities in all cases are less than 10 percent.

A similar set of probabilities is presented in the AFCRL tables for the occurrence of a Class 1 flare or greater on the second day. Obviously, the probabilities are much higher in all cases. In the extreme case of the largest sunspot group where a flare of importance Class 2 or greater occurs on one day, the probability is 93 percent that a flare of Class 1 or greater will occur on the next day.

AFCRL investigators are presently collecting historical statistical data on radio brightness temperature and magnetic classification of sunspot groups. When these two parameters are added to the present parameters of sunspot group size and flariness (tendency to produce a flare), the probability that a flare of a given magnitude will occur on the next day can be stated with even greater assurance.

Contact: Alfred E. Reilly Telephone Extension 4207

Since 1964 Mr. Alfred E. Reilly has been a Research Physicist with the Space Forecasting Branch of AFCRL's Space Physics Laboratory where he examines space data for evidence of physical and statistical relationships.

Mr. Reilly was graduated from Boston College in 1952 with a Bachelor's degree in Physics, cum laude. He then completed all course requirements for a Master's Degree in Physics at the Boston College Graduate School while employed as a Graduate Teaching Assistant. From 1954 to 1956, he was employed at AFCRL in the design and development of the TACS-BADGE System. Following active duty in the armed forces from 1956 to 1958, he spent five years in AFCRL's Astrosurveillance Sciences Laboratory designing and optimizing specialized detection experiments. From 1963 to 1964 he conducted studies of the effects of solar activity on the terrestrial ionosphere for the Upper Atmosphere Physics Laboratory of AFCRL.

Mr. Reilly is a member of the American Geophysical Union and of Sigma Pi Sigma. He has a number of scientific publications to his credit.

Dr. Gordon Wares has made a number of contributions to the spectroscopy of high temperature gases. This work, now a part of the reference literature, helps astrophysicists identify the sources of spectral lines emitted by solar and stellar gases.

SPACE PHYSICS LABORATORY, AFCRL

ionization extremes at room temperatures

The beam-foil technique is one of the most important new spectroscopic techniques to come along in several decades. Extremes of ionization, ordinarily found only in stellar interiors, the solar corona, or in nuclear fusion reactions, can be created in the laboratory under controlled conditions. First introduced in 1964 and intensively developed by Stanley Bashkin's group at the University of Arizona, the beam-foil technique is now producing results of particular value to plasma physicists. The research is applicable to numerous plasma oriented military functions and operations but the major emphasis at AFCRL is on improving techniques for the remote sensing of plasmas such as solar flares and studies of plasmas of the types found in vehicle reentry and high altitude nuclear bursts.

The technique consists of passing a beam of ions through a thin foil (only a few millionths of an inch thick). When the beam emerges from the other side, additional electrons may have been stripped from the ions and some of the remaining electrons may have been temporarily excited to higher energy levels. As they fall back to normal levels, they emit characteristic lines and the beam becomes luminous.

The intensity of the spectral lines quickly decays and the rate of decay—or radiative lifetime—of a particular ionized species is of great interest to the physicist. He uses the results to interpret spectrograms taken of the sun and stars. From the interpretation, he learns quantitatively the composition of stellar and solar plasmas and gains insight into the physical processes that produce visible and UV emissions. A question that he might ask is "How many quadruply-ionized oxygen ions must be present in a plasma to produce a line of a certain intensity?" The answer is

given by the corresponding radiative lifetime. The shorter the lifetime (or the bigger the absolute "f-value"), the smaller the number of ions required to produce a line of given intensity. The f-value or "absolute transition probability" is the crucial optical constant required to find the actual number of atoms, molecules, or ions from the measured intensity of a spectral line in some "remote" gas–star, nebula, reentry plasma sheath, fireball, hypersonic flow, high Mach number propulsion system, or solar corona.

Over the last few years, Dr. Gordon Wares and his group have used AFCRL's 3-Mev Van de Graaff generator as an ion source for these studies. They have measured the radiative lifetimes of scores of excited energy levels of oxygen and nitrogen in various states of ionization. The experimental setup consists of the ion beam, a thin carbon foil for ion stripping, and a spectrographic detector which can be repositioned to varying distances (over a range of a few centimeters) from the foil. The measurements take place in a 10^{-6} torr vacuum.

The lifetime of an ion in a particular excited energy level is extremely short–typically a few nanoseconds. The property of interest is the intensity decay rate for each spectral line, expressed as a function of time as the population of its upper excited energy state dies away. The idea is analogous to a certain "life expectancy" of human beings, taken here to be when 1/e = 1/2.718–when approximately 37 percent remain. Here, because the speed of the ions passing through the foil is known, the radiative lifetime of any line is proportional to the number of millimeters downbeam from the foil required for that line to decay to 1/e ~ 37% of its initial intensity.

Dr. Wares' group has determined the radiative lifetimes for the upper excited states of 37 known emission lines of singly, doubly, triply, quadruply, and quintuply ionized oxygen. In the process they have discovered 5 new emission lines of oxygen ions. For singly to quadruply ionized nitrogen, they have established the radiative lifetimes for 21 known lines and have discovered 5 new nitrogen ion lines. Similar studies are presently being made of the radiative lifetimes of carbon and neon ions. These AFCRL measurements provide experimental confirmation for the absolute scale of isoelectronic sequences of computed f-values, a standard reference compiled and maintained by the Bureau of Standards.

Contact: Dr. Gordon W. Wares
Telephone Extension 3068

Dr. Gordon W. Wares is a research astrophysicist at AFCRL's Space Physics Laboratory. In his current work, he uses shock tube data, obtained on the behavior of elements at ultrahigh temperatures, as a standard for comparing the spectral lines from stars and galaxies to determine the elemental composition of stars.

In 1933 Dr. Wares received a Bachelor of Science degree in mathematics, magna cum laude, from the University of Washington. Following three years at the University of California as a graduate student, university fellow, and teaching fellow in astronomy, Dr. Wares transferred to the Yerkes Observatory of the University of Chicago where he earned two astrophysics degrees, Master of Science in 1937 and Ph.D. in 1940.

After teaching at Brenau College, Georgia, (1939-1941) and Milwaukee State Teachers College (1941-1942), he accepted a commission in the U.S. Air Force to instruct in the Ground School. From 1944 to 1945, he worked on the electromagnetic separation of isotopes in the University of California Radiation Laboratory, and from 1945 to 1951 he worked at the Naval Ordnance Test Station in California on the direct determination of aeroballistic coefficients of spin-stabilized rockets.

During his academic years, Dr. Wares was elected to Sigma Pi Sigma, Phi Beta Kappa, Sigma Xi, the American Astronomical Society and the Royal Astronomical Society. He is also a member of RESA, and has published more than 20 articles in scientific journals.

scintillation data and satellite communications

IONOSPHERIC PHYSICS LABORATORY, AFCRL

Planning of satellite systems for aircraft communications, control, and navigation is now well underway. The technology for the VHF and UHF systems is available, but decisions by design engineers on basic system parameters must still be made. Their decisions will be based on considerations of ionospheric effects. The AFCRL Radio Astronomy Observatory at Hamilton, Mass., is the largest single contributor of data on those ionospheric effects known as scintillation. Data compiled by AFCRL over the past 10 years have already been widely used by the designers of present operational military and civilian communications satellites.

Scintillation is nothing more than the increases and decreases in the amplitude of a signal that is passed through the ionosphere. These variations are caused by irregularities in ionospheric density. Signal fluctuations may be rapid, with a period of a few seconds, or may be slow, with a period of several minutes. At all latitudes, signal fading reaches its maximum depth near midnight.

The designer must have a knowledge of signal fading under all possible operating conditions. He wants to know the dB fading that can be expected during quiet and active magnetic periods, by seasons, at a given time of day, and for all geographic latitudes. With this knowledge, he can optimize trade-offs between power and weight of equipment and acceptable periods of systems blackout.

Most scintillation research outside of Soviet countries is planned, or coordinated, through the Joint Satellite Studies Group, a voluntary cooperative American-European effort. Dr. Jules Aarons, head of AFCRL's Radio Astronomy Branch, took the initiative in organizing this Group in 1958 soon after the launch of the first Soviet Sputnik. Since then, AFCRL scientists have published, or presented, scores of papers on various aspects of the subject. Other

scientists participating in the cooperative effort have produced an equal or greater number of papers.

The results of these studies have now been summarized in a recently issued report, "A Survey of Scintillation Data and Its Relationship to Satellite Communications." In this report (prepared at the request of AGARD, the NATO advisory group on R&D), the AFCRL authors have translated their results into terms meaningful to systems designers.

The report, for example, assists the engineer in dealing with the following problem: Consider an aircraft over the North Atlantic, depending on FM voice communications and pulsed navigation systems where VLF signals are relayed between the aircraft and a synchronous satellite. What prediction can be made for fading greater than 3, 6, or 10 dB below normal signal level? In this simple case, based on 1,100 hours of observations of the LES-5 satellite at 228 MHz, the beacon on the satellite faded 3 dB below its expected intensity only about 0.15 percent of the time. However, at other geographic latitudes where the scintillation index may be greater, the signal may fall below the 3 dB level 20 percent of the time, or below the 10 dB level 2.5 percent of the time. Deep fades are observed in the auroral and polar regions as well as along the geomagnetic equator.

The scintillation index referred to in this example is in itself a new concept, having its origin in 1966 when AFCRL was asked by COSPAR (Committee on Space Research, the major international association of atmospheric and space scientists) to formulate a standardized method for reporting levels of scintillation. A scintillation index must be one that describes amplitude fluctuations in terms of some average value, using a uniform set of procedures for deriving a scale of values. The index developed by AFCRL is compatible with the needs of both the ionospheric physicist and the communications engineer. The international adoption and use of this index could represent by itself an AFCRL contribution of major importance.

Contact: Dr. Jules Aarons
Telephone Extension 2944

Dr. Jules Aarons is Chief of the Radio Astronomy Branch of AFCRL's Ionospheric Physics Latoratory. He is currently studying radio star and satellite scintillation at various latitudes (Greenland, Massachusetts, Puerto Rico), making observations on the Early Bird synchronous satellite, and studying radiation from the sun in the microwave region. As a member of cooperating international groups, he is concerned with solar terrestrial relationships and observations on satellite beacons.

Dr. Aarons received his B.S. in Education from the City College of New York in 1942 and his M.S. in Physics from Boston University in 1950. In 1954 he received his Ph.D. in Geophysics from the University of Paris.

Dr. Aarons has served as Program Director of two NATO Advanced Study Institutes (one in 1961 on Radio Astronomical and Statellite Studies of the Atmosphere; the other in 1964 on Solar System Radio Astronomy). He has edited books and special issues covering the results of these programs. In addition, approximately 60 articles on his work have appeared in various scientific publications. He is a member of the American Geophysical Union, the American Astronomical Society, the IEEE, and the American Association for the Advancement of Science. He is also a fellow of the Royal Astronomical Society.

PROJECT: USE IT

(Undeveloped Scientific Exploitation of Inventions & Technology)

LT COL LUDWIG LIPPERT, Staff Judge Advocate, OAR

The Department of Defense spends approximately eight billion dollars a year for research and development. The results of these research efforts represent a significant and potential proprietary asset for the United States Government. To obtain maximum benefit from this asset, invention disclosures resulting from this research are obtained and processed through various patent rights programs. However, Government patent protection is sought for only a small percentage of the invention disclosures received and processed. For instance, in Fiscal Year 1965 the Department of the Air Force filed patent applications on 8% of the invention disclosures submitted to it. This 8% figure also applies to the patent protections sought by HEW and may be compared to the 13% sought by the Department of Commerce and the 17% by NASA. In the same year, the Army, Navy, and Air Force received 7,019 invention disclosures. Of these, patents protection was sought for 1,089. For the three fiscal years of 1963, 1964, and 1965, no protection was sought for approximately 20,000 invention disclosures received by all Government agencies.

Even though these invention disclosures were not patented, they contain information in capsule form which can be read quickly and digested for further utilization. It is recognized that this information and other data are available in the contractors' research reports and that a large percentage of these disclosures may not be legally patentable, or even have other useful applications. Nevertheless, the ideas and work contained in these invention disclosures represent a teeming potential wealth for the United States Government which, at a minimum cost, can be more effectively tapped than at present.

The author has selected a few of these invention disclosures which have not been protected by patenting processes and has prepared a brief description to give the gist of the idea of the invention. (See "Invention Disclosures" in the Reader's Interchange of this issue.) Some imagination and scientific curiosity will be needed by the reader to visualize the possible applications of the inventions for other uses, and the required adaptations or modifications. Perhaps, the reader will be able to conceptualize the other applications in a generalized sense for roles, goals, and objectives which are still unverbalized. Our purpose will be to stimulate exploitation of this information by providing sufficient identification on the location of the technical supporting information.

An example of the imagination and scientific curiosity that will be needed may be found in the invention disclosure in which a researcher developed a noise generator for the Air Force. The uniqueness of this invention is that acoustical noise can be produced to duplicate various jet or rocket-type engine noises. The particular noise to be duplicated can be created by adjusting the machine. The primary purpose of the machine is to test the molecular rearrangement, fatigue, and disintegration of metal parts caused by acoustical loads. One suggested adaptation of this device was for counter-insurrection use. It was suggested that the generator could be mounted in a large case which could be helicopter-carried or truck-transported to the mouth of a cave complex. The generator would be tuned to a noise frequency unacceptable to human tolerance and the noise would be directed into the cave. Whether the device would work in this manner would require scientific study and evaluation.

This example is given to demonstrate the potential of adapting items and recognizing their uses for a different purpose in the developments of another service or scientific discipline. It is hoped that any reader, who believes he has an idea, useable elsewhere in the Air Force, will submit the idea to the author or PGRO for possible publication in the Reader's Interchange. The uses for these invention disclosures and ideas would be similar to the afterburner on an aircraft where the expended gases are reburned for added thrust. These nonprotected invention disclosures and ideas may very well be the answer to the problem of some other scientific discipline or laboratory, agency, or service. This asset of the United States should not be squandered. We should USE IT!

READER'S INTERCHANGE

Research Advances

CdS Thin Film Solar Cells

Development: CdS thin film solar cell which converts light into electrical energy. A film of polycrystalline CdS is deposited on a thin conducting substrate; thus the size of a single crystal does not limit the size of the cell. Cu_2S is formed through chemical conversion. Due to the high absorptivity of Cu_2S and its favorable band gap, reasonable efficiencies are possible (4% to 6% with power to weight ratio of 100 watts per pound and at cost of $50 to $100 per watt). The cell has a desirable degree of flexibility and ruggedness; it can be mass-produced and is relatively lightweight.

Application: The cell could be used as a source of power in spacecraft and communication systems.

Sponsor and Project Identification:

ARL (ARX) Project No. 7885 Coupling Report No. ARL 70-2
Project Scientist: Major D. R. Stukel
Telephone: Area Code 513 255-3654
AUTOVON 78 - 53654

Infrared Detectors

Development: A thin film thermocouple detector capable of detecting emissions in the middle and far infrared. This detector has a nanosecond response time and does not require cooling below room temperature. Its noise equivalent power is around 10^{-7} watts/Hz.

Application: Wherever the tradeoff between weight and power associated with cooling outweighs a slight reduction in detector sensitivity.

Sponsor and Project Identification:

AFOSR (SRPP) Project No. 9767 Coupling Report No. AFOSR 70-2
Project Monitor: Dr. Marshall C. Harrington
Telephone: Area Code 202 694-5454
AUTOVON 22-45454

Coupling of Shock Wave to Chemical Reaction

Development: The coupling of a chemical reaction to an incident shock wave in stoichiometric hydrogen-oxygen mixtures highly diluted with argon. The coupling mechanism occurs through pressure waves generated by the chemical reaction initiated by the shock. The reaction front, initially far behind the incident shock, overtakes the shock wave and coalesces with it to form a quasi-stationary detonation wave. The pressure waves accelerate the shock waves, causing succeeding elements of gas to react in shorter time intervals and leading to the formation of a relatively steep front.

Application: Study of the interaction between chemical reaction and pressure fronts may contribute to the solution of the problem of oscillatory combustion.

Sponsor and Project Identification:

ARL (ARC) Project No. 7023 Coupling Report No. ARL 70-9
Project Scientist: Dr. K. Scheller
Telephone: Area Code 513 255-4611
AUTOVON 78 - 54611

Solid State Signal Processor

Development: A prototype of a solid state microwave signal processor allows the mixing of two bulk waves to create an E field in a crystal; the readout of the E field is the convolution of the two signals. Although the experiment was carried out at UHF wavelengths, using a 1" x 3/16" x 3/16" crystal of lithium niobate, VHF to SHF (super high frequency) wavelengths may also be used. As in holography, both signals are derived from the same source: one signal carries intelligence embedded in the normally expected noise; the other signal is the unperturbed original waveform. The convolution process forms the average product of the reference signal and the intelligence-modulated signal; thereby the noise is virtually eliminated. Advantages over present devices include: (1) very high s/n ratio, (2) low input power required, (3) very small energy loss, (4) survivability, (5) very small size, and (6) variable delay.

Application: To (1) terminal guidance, (2) onboard satellite signal processing, (3) radar ECM and ECCM signal processing, (4) sonar target definition.

Sponsor and Project Identification:

AFOSR (SREE) Project No. 4751 Coupling Report No. AFOSR 70-3
Project Monitor: Captain John K. Kantak
Telephone: Area Code 202 694-5518
AUTOVON 22 - 45518
Project Scientist: Dr. C. Quate,
Microwave Laboratory
Stanford University, Stanford, California 94305
Telephone: Area Code 415 327-7800

TO OUR READERS

Requests for further information from institutions and individuals in the U.S.A. may be either mailed to the addresses below, or telephoned to the individuals named as "Contact" at the end of each article. If no organization follows the name of the contact, assume that it is the same organization given under the title of the article.

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L G Hanscom Field
Bedford, Mass. 01730
Tel: Area Code 617 861-4441 + Ext.*
AUTOVON 478 + Ext.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
1400 Wilson Blvd.
Arlington, Va. 22209
Tel: Area Code 202 OX 4 + Ext.
AUTOVON 22 + Ext.

AEROSPACE RESEARCH LABORATORIES
Wright-Patterson AFB
Ohio 45433
Tel: Area Code 513 255 + Ext.
AUTOVON 78 + Ext.

OFFICE OF RESEARCH ANALYSES
Holloman AFB
New Mexico 88330
Tel: Area Code 505 473-6511 + Ext.
AUTOVON 867 + Ext.

THE FRANK J. SEILER RESEARCH LABORATORY
USAF Academy
Colorado 80840
Tel: Area Code 303 472 + Ext.
AUTOVON 259 + Ext.

EUROPEAN OFFICE OF AEROSPACE RESEARCH
Box 14
FPO New York 09510

Requests for further information from institutions and individuals in Latin America should be addressed to:

HQ OAR (PGF)
1400 Wilson Blvd.
Arlington, Va. 22209

Detailed documentary reports may be obtained from:

CLEARINGHOUSE
U.S. Department of Commerce
Springfield, Virginia 22151

DEFENSE DOCUMENTATION CENTER†
Cameron Station
Alexandria, Virginia 22314

*Extension numbers appear with the "Contact" at the end of each article
†Qualified requesters only

OAR (PGRO)
1400 Wilson Blvd.
Arlington, Va. 22209

UNITED STATES AIR FORCE
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
DEPARTMENT OF THE AIR FORCE

★ AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
★ AEROSPACE RESEARCH LABORATORIES
★ LATIN AMERICAN OFFICE OF AEROSPACE RESEARCH
★ AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
★ OFFICE OF RESEARCH ANALYSES
★ THE FRANK J. SEILER RESEARCH LABORATORY
★ EUROPEAN OFFICE OF AEROSPACE RESEARCH